

REPORT NO. CG-D-1-78



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PROJECTED COMMERCIAL MARITIME ACTIVITY IN THE WESTERN ARCTIC

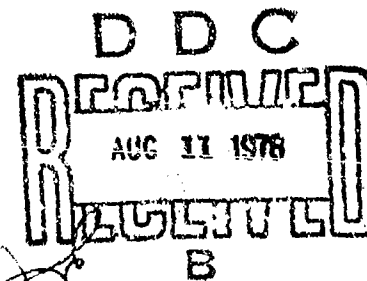
AD A057410

J.P. Welsh
U. S. Coast Guard Research and Development Center
Avery Point, Groton, Connecticut 06340



October 1977

Final Report



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PREPARED FOR
U.S. DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD
OFFICE OF RESEARCH AND DEVELOPMENT
WASHINGTON, D.C. 20590

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D. L. Birkinfr

DONALD L. BIRKINFR, Ph.D., P.E.
Technical Director
U.S. Coast Guard Research and Development Center
Avery Point, Groton, Connecticut 06340

1. Report No. 18 US CG D-1-78	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle 6 PROJECTED COMMERCIAL MARITIME ACTIVITY IN THE WESTERN ARCTIC	5. Report Date 11 October 1977	6. Performing Organization Code
7. Author(s) 10 J. P. Welsh	8. Performing Organization Report No. 14 CGRDC-27/77	9. Work Order (if RAS)
10. Performing Organization Name and Address United States Coast Guard Research and Development Center Avery Point Groton, CT 06340	11. Contract or Grant No. 786201.1	12. Type of Report and Period Covered 9 Final Report
12. Sponsoring Agency Name and Address Department of Transportation United States Coast Guard Office of Research and Development Washington, DC 20590	13. Sponsoring Agency Code	
15. Supplementary Notes		
16. Abstract Commercial marine activity will increase dramatically in the Western Arctic commencing about 1980. This is based on the projected rate and extent of exploitation of the natural resources (particularly petroleum). The consequence of increased maritime traffic will be continued growth of demand for the marine services provided by the U.S. Coast Guard. The services required are primarily in the areas of icebreaking, search and rescue, aids to navigation, and marine environmental protection. To meet these demands, a Polar Vessel Information System will have to be developed and operated by the U.S. Coast Guard.		
17. Key Words Arctic, polar, vessel traffic, icebreakers, maritime activity, routing, ice information		18. Distribution Statement Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161
19. Security Classif. (of this report) UNCLASSIFIED	20. Security Classif. (of this page) UNCLASSIFIED	21. No. of Pages 81
		22. Price

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
in ²	square inches	6.5	square centimeters	cm ²
ft ²	square feet	0.09	square meters	m ²
yd ²	square yards	0.8	square meters	m ²
mi ²	square miles	2.6	square kilometers	km ²
	acres	0.4	hectares	ha
MASS (weight)				
oz	ounces	28	grams	g
lb	pounds short tons (2000 lb)	0.45 0.9	kilograms tonnes	kg t
VOLUME				
teaspoon	teaspoons	5	milliliters	ml
Tablespoon	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
cu ft	cubic feet	0.03	cubic meters	m ³
cu yd	cubic yards	0.76	cubic meters	m ³
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* 1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 225, Units of Weights and Measures, Price \$2.25, SO Catalog No. C13.10.286.

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	2.2	feet	ft
km	kilometers	0.6	miles	mi
AREA				
cm ²	square centimeters	0.16	square inches	in ²
m ²	square meters	1.2	square yards	yd ²
km ²	square kilometers	0.4	square miles	mi ²
ha	hectares (10,000 m ²)	2.5	acres	ac
MASS (weight)				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	st
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m ³	cubic meters	35	cubic feet	cu ft
m ³	cubic meters	1.3	cubic yards	cu yd
TEMPERATURE (exact)				
°C	Celsius temperature	5/9 (then add 32)	Fahrenheit temperature	°F

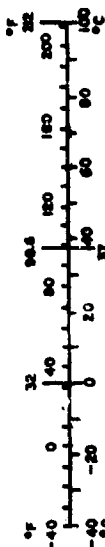


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1.0 CONCLUSIONS AND RECOMMENDATIONS

1.1 Conclusions

Commercial marine activity will increase dramatically in the Western Arctic commencing about 1980. This conclusion is based on the projected rate and extent of exploitation of the natural resources (particularly petroleum) of the Western Arctic. The consequence of this increased maritime traffic will be continued increasing demand for the marine services provided (under statutory authority) by the U. S. Coast Guard. The services required are primarily in the areas of search and rescue, aids to navigation, icebreaking, and marine environmental protection.

One of the stated objectives of the Polar Vessel Information System program is to develop an environmental conditions advisory and coordination facility service for commercial vessel traffic and Coast Guard icebreakers in the Western Arctic. The development of an environmental conditions advisory and coordination facility service is the statutory responsibility of the National Weather Service (NWS). NWS, in 1974, initiated a program addressing the need to improve their capabilities to provide ice information services to the commercial fleet in the Western Arctic. Thus the Coast Guard does not need to address this objective.

The demand for Arctic search and rescue services will be great and ever increasing in step with the offshore oil development and the introduction of icebreaking oil tankers and LNG carriers.

Concurrent with the introduction of oil and LNG carriers and offshore drilling will be increased allocation of Coast Guard resources to the marine environmental protection functions. A part of this responsibility not immediately obvious is the increased requirement for marine inspection to assure compliance and thus prevention of major marine disasters in the hostile but fragile Arctic waters.

Increasing numbers of large and specialized vessels which will attempt year round transit of ice-covered Arctic waters will require greatly expanded vessel traffic control and extensive aids to navigation. In these areas the Coast Guard must carry the greatest proportion of responsibility.

The magnitude of projected maritime activity will require a centrally located facility which effects operational awareness and control of all functions required (particularly of an advisory nature) to expedite marine transportation. This coordination function is vitally important to the national interest in the Western Arctic. Exactly what organization (agency, etc.) will perform this coordination function is not known. The Coast Guard, by virtue of experience and statutory responsibility in most of the expected marine functions required, have the necessary capabilities to be the lead agency.

1.2 Recommendations

The objective of the Polar Vessel Information System program should be revised by deletion of the requirement to develop an environmental conditions advisory and coordination facility for commercial vessel traffic and Coast Guard

icebreakers in the waters of the Western Arctic. In place of the deleted part, the objective could be changed to consider the development of a facility for coordination of advisories and control of Arctic maritime activity. CCGD17 in Juneau, Alaska, is a possible location for such a facility. The scenario section of this report describes what such a facility might be like.

Funding should continue for this program to support the preparation of a technical development plan (TDP) concentrating on defining the scope of potential search and rescue, aids to navigation and marine environmental protection problems and development of an Arctic marine traffic coordination facility. Additional to the above is a more detailed look at requirements as they affect the almost certain need for new icebreakers of various classes and other capital investments particularly as related to provision of icebreaking services.

2.0 INTRODUCTION

On 30 August 1976 the Commanding Officer, Coast Guard Research and Development Center received a TOR (Tentative Operational Requirement) for Coast Guard Ice Operations in the Western Arctic. The TOR contained statements of need, problem, objective, approach guidelines, time frame and administrative coordination.

2.1 Need

The United States has been concerned with the Polar regions for over one hundred years. The Coast Guard, through its Revenue Cutter Service heritage, has been an agent of the Federal Government in the ice-covered Alaskan waters since 1867. The responsibilities have been enforcing laws and treaties, conducting ice operations in support of the Department of Defense, providing search and rescue capability, aids to navigation and marine environmental protection. Cooperation with other Federal and state agencies through utilization of unique Coast Guard resources have well served the goals of the national interest in the Arctic.

The United States is involved in an economic upheaval caused primarily by an energy crisis. The crisis is in terms of both increasing cost of fuel and uncertainty of supply. The Executive Branch of the Federal Government is committed to directing the nation toward more, if not total, reliance on domestic fuel supplies. The estimated reserves on the North Slope and under the continental shelves of Alaska are potentially the largest untapped petroleum source in North America. Various estimates of recoverable reserves (including the Mackenzie Bay area and the Canadian Archipelago) range up to 200 billion barrels of oil and 8.5 trillion cubic meters of gas.

Development of these resources will entail extensive offshore surveys, exploratory and production drilling, location of sites for, and construction of harbor facilities and maintaining a yearround marine transportation system. This development will place an extraordinary demand on the Coast Guard for many services in addition to icebreaker support. These potential demands require that the Coast Guard carefully consider the ramifications of economic development of the Western Arctic and through appropriate planning be prepared for action.

2.2 Problem

Increased economic activity and development in the Western Arctic particularly Alaska will affect Coast Guard icebreaker operations. The effects will be mainly in the Bering, Chukchi and Beaufort Seas. Navigation off the Alaskan coast will be especially challenging to both commercial vessels and Coast Guard icebreakers. Changing ice and meteorological conditions, shallow waters, inaccurate charts, limited and often inadequate aids to navigation are but a sampling of the problems to be considered.

Scientific knowledge of the ecology of the Western Arctic is very limited. This is particularly true for the Chukchi Sea and Beaufort Sea areas. They are considered to be ecologically very fragile. Increasing our scientific knowledge of the Arctic environment and improving our techniques in applied ice research are necessary to develop plans for meeting future Coast Guard requirements. The expanding activity in the Western Arctic will require a multiprogrammed approach to establish the Coast Guard's roll in the economic development of the 49th state.

2.3 Objective

The objective of this program is to develop a Polar Vessel Information System including an operational/ice/meteorological service for commercial vessel traffic and Coast Guard icebreakers in the waters of the Western Arctic off the coast of Alaska.

2.4 Approach Guidelines

The approach should be to develop a 5 to 10-year plan, beginning by integrating the present information on vessel traffic densities and routes, vessel routing systems, ice and weather forecasting systems and Polar ice research programs into a current report of projected commercial maritime activity and requirements in the Western Arctic. This report will serve as background for operational planning. Next should follow a TDP (Technical Development Plan) which addresses the implementation of the appropriate technologies. Consideration should be given to the use of aircraft and satellite remote sensing techniques, weather and ice information resources from other agencies, facility requirements, computer modeling of ice dynamics, vessel routing, communications and aids-to-navigation requirements in ice-covered waters. Finally, a separate planned approach for meeting Coast Guard operational requirements in the Arctic is expected.

2.5 Time Frame

Initial studies should commence in FY77 with continued funding for FY78 and FY79 to complete background studies and development of the technical plan.

2.6 Administrative

The Ocean Operations Division of the Office of Operations is the program monitor with CDR M. J. MOYNIHAN serving as the point of contact for coordination.

The above describes the overall program as provided by the Office of Operations. From the approach guidelines it is clear that two products are required. They are:

- a. Current report of projected commercial maritime activity and requirements in the Western Arctic (present document); and
- b. A separate planned approach for Coast Guard operational requirements in the Arctic (TDP) after the operational requirements have been stated.

Briefly, in summary, the Office of Operations requires two distinct studies which address particularly ice operations in the Western Arctic. This report considers the first study requirement which will naturally provide a basis for and lead into the second study.

2.7 Approach

The approach taken in this report is to present summary type information which has been obtained from the literature, experience and personal communications. The outline for organization and presentation of information is topical rather than spatial or temporal. An extensive bibliography has been compiled and is included. Because the conclusions are in the form of projections of future events, caveat emptor applies. In this case it is not the buyer beware, but the potential planner who must exercise caution.

The major topics to be presented are arranged in the following order:

- a. Vessel traffic densities and routes;
- b. Present vessel routing systems;
- c. Ice and weather forecasting; and
- d. Polar ice research programs.

But before these are presented, a little background on Alaska.

2.8 Alaska

Alaska is from an Aleutian word meaning "Great Land" and great it is indeed. Alaska is the largest state in the Union (586,412 square miles) with an extreme length of 2200 miles and breadth of 1200 miles. The coastline of 6640 miles is, to understate, impressive. This incredibly long coastline suggests the magnitude of potential aids to navigation and marine environmental protection problems that increased maritime activity could bring.

Alaska is probably the last real land bargain. In 1867 the United States purchased Alaska from Russia for \$7.2 million (\$12.28 per square mile or 1.92 cents per acre). At the time many Americans thought the purchase unwise, even foolish, because they considered Alaska a frozen wasteland and therefore valueless. Of course this attitude was modified in 1896 with the

discovery of gold in the neighboring Yukon territory, at Nome (1899), and later in Fairbanks (1902). Unfortunately the lasting benefits or gains to Alaska were very small. In 1969 major oil companies bid an aggregate amount of \$900 million for oil land leases. A splendid return on the \$7.2 million even considering inflation and present value theory.

Southeastern Alaska has deep fjords and mountains that seem to rise directly from the water's edge. Mount McKinley (20,320 feet) near Anchorage is the highest peak in all of North America. Little Diomed Island in the Bering Strait is only two miles from the USSR. Katmai on the Alaska Peninsula has active volcanoes while just a little east and south are expansive perennial ice fields. These extremes or contrasts serve only as tantalizing samples of the wondrous variety that Alaska can offer. These contrasts also point out the paradox of scale that affects the economics of the state. The tremendous land area and very long distances on one side and small markets and limited overhead capital on the other side result in high cost operations which inhibit economic activity.

Distribution of population must also be considered from the economics viewpoint. The population is found in small communities near the coast or along the main rivers. Thus, Alaska is essentially a maritime state which has not developed a surface transportation system suitable to exploit the interior economic potential. The population can be generally divided into two fractions; native and nonnative. In practice this division also coincides with residence in smaller communities and the major cities, respectively.

On top of the above inhibiting factors to economic development are the topographic (physiographic) and climatic constraints. In general the state can be divided into four major physiographic areas (Figure 1). They are from south to north:

- a. Pacific mountain province from southeastern Alaska through the Aleutian Chain;
- b. Interior Basin which is the intermountain plateau in between the Pacific and Rocky Mountain systems;
- c. Brooks Range (northern extension of the Rocky Mountains) which runs eastwest across Alaska north of the Arctic Circle; and
- d. Arctic slope (interior plains) which is north of the Brooks range and extends to the coast of the Arctic Ocean. The climatic regions are roughly congruent to the topographic regions.

In general the climatic conditions can be described as essentially either maritime or continental with some areas of overlap. The climate in the various regions is primarily dominated by the two mountain systems, variation in ocean temperatures, oceanic storms and generally variable moisture conditions. The narrow belt along the Pacific coast is moderated (warmed) by the Japan current. This section of coastline has the characteristics of a northern temperate maritime zone. All of the rest of the Alaskan coastal areas have either sub-Arctic or Arctic characteristics.

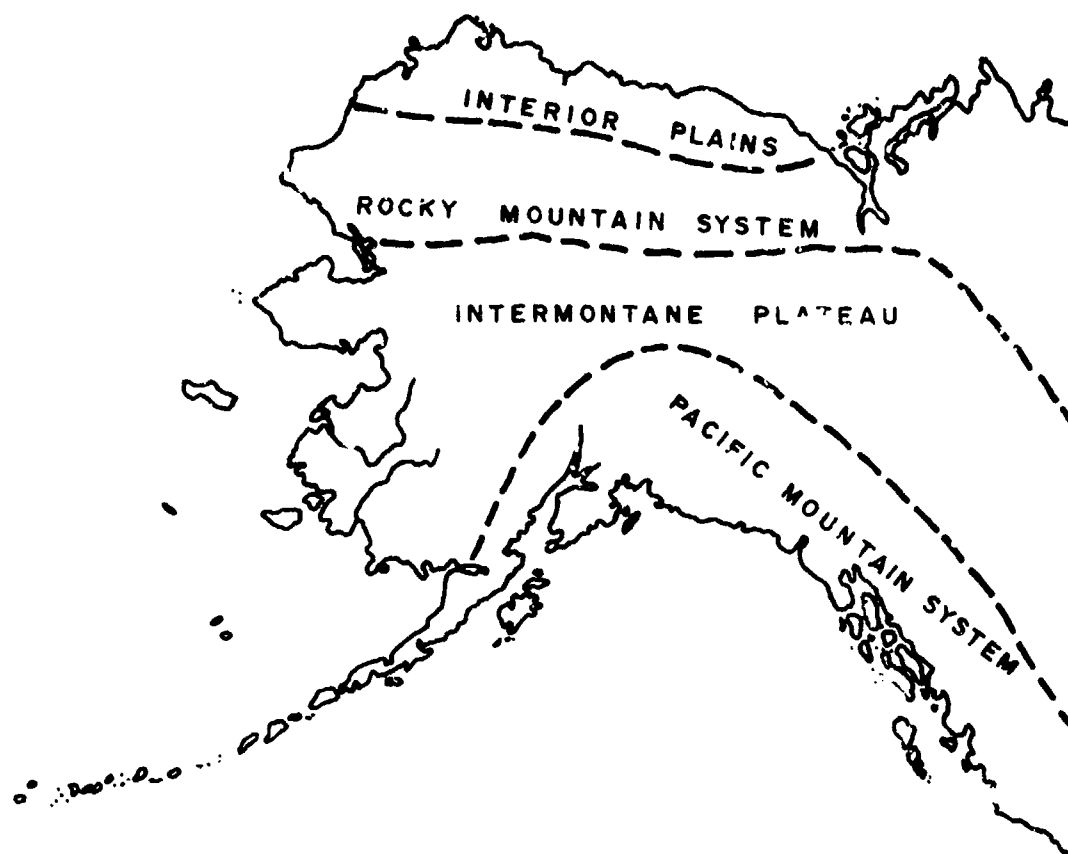


FIGURE 1
PHYSIOGRAPHIC DIVISIONS OF THE STATE OF ALASKA

The marine conditions are for the most part characterized by the seasonal occurrence of sea ice. Sea ice can be described or classified in many ways for many purposes. Along the coastline fast ice is the predominant scene for most of the year north of the Arctic Circle. The sea ice which grows and melts throughout the year is often classified by its growth history. In general, the new ice season begins in September. As the ice thickens, names like dark nilas and light nilas are used to describe it. Ice of one year's growth is called annual or first-year ice, if it survives the melt season it becomes second year and so on, to multiyear pack ice.

For short periods the conditions may remain calm and the ice is not smashed together or deformed. At other times the ice is in constant motion, caused by the wind and current, resulting in violent collisions of individual pieces piling up and being submerged and forming into pressure ridges and hummocks. The flip-flop of calm and holocaust conjure images of unbelievable destructive force and impenetrability while also creating sculptural forms of sublime beauty both intensely rugged and supremely delicate.

The contrasts are as distinct at sea as they are on land. The cold, with a blowing wind and snow, can be unpleasant to the point of pain, but let the wind die and the sky clear and the cold is invigorating to both the body and the spirit.

Storms at sea in the Arctic are variable in occurrence and intensity. Some are severe in the extreme, life threatening; while others are almost benevolent.

The Bering and Chukchi Seas are shallow; actually the water depths are essentially that of the continental shelf. The shelf is rather narrow in the Beaufort Sea. Shallow water is a navigation problem for larger, deeper draft vessels. Because of the shallow water problem, there are few potential routes.

The topography, sea ice and climate more than any other factors conspire to make almost everything more expensive and more difficult to do in the Western Arctic. But because the world is resource hungry and Alaska has abundant resources, development is inevitable.

3.0 VESSEL TRAFFIC DENSITIES AND ROUTES

The density of commercial Arctic vessel traffic is dictated by many things. Chief among these things is the demand for petroleum. The demand establishes the lower bounds for deciding what combination of ways of exploration, extraction, transportation, scheduling and distribution are economical and profitable. Ships have long figured as a most economical and therefore profitable mode of transport for numerous commodities. Exploitation of the resources of the Western Arctic and transport of the derived commodities to the market will depend on ships. Pipelines, railroads, airplanes, trucks and novel things like air cushion vehicles will all be part of the complete transportation system but ships will carry the major proportion.

This section of the report will examine some projections and discuss the implications for the more important commodities that will make up future marine cargoes from the Western Arctic. Routes will be considered as well as the probable fleet mix required. This discussion will provide the basis

for projecting the need for icebreaker support and the need for other Coast Guard provided services such as aids to navigation, search and rescue and marine environmental protection.

3.1 Demand

It will be clear by the end of this section that commercial vessel traffic will increase and in turn will require a major commitment and presence from the U. S. Coast Guard in the Western Arctic. The demand for natural resources will fuel the increased maritime activity. Various resources will be exploited and will become the cargoes for commercial marine operators.

3.2 Cargoes

The major cargoes will be oil, liquified natural gas (LNG), coal and copper. Also anticipated are shipments of ore minerals; fluorite, tin, tungsten, graphite, mercury and antimony.

Oil and gas will have the greatest impact on economic development and will be proportionally the greatest bulk of all cargoes outbound from the Western Arctic. The other cargo types will reflect as incremental increases to the overall marine traffic density.

As usual great confusion begins when data is collected from many sources where various units are used. To minimize and hopefully avoid most of the unit problems, all solid type cargoes (the ore minerals) are reported in metric tons, oil is reported in barrels (bbls) and metric tons, and LNG is reported in cubic meters. Because the barrel and ton are such familiar units, the International System of Units has not been used. Each cargo will be discussed in the following paragraphs.

3.3 Petroleum

Oil is the most sought after energy source in the world, It is convenient to use and is "mother" of an infinite variety of products from medicines to plastics. There are few if any commodities which can command the large capital investments that oil can. Thus the discovery and development of large oil fields are important economic pacesetters. This has certainly been true for the North Slope of Alaska. The potential of the offshore prospects are many times greater than the estimated landward North Slope discoveries (estimated to be 70% of the total). The economic potential of immense reserves of oil is the special ingredient needed to develop an otherwise uninviting and inhospitable region. For perspective, Figure 1A is a generalized location map of exploration and development for the Arctic.

3.4 Reserves

The petroleum reserves of Alaska are tremendous. By comparison the proven recoverable oil worldwide is 600 billion barrels of which 40 billion barrels are in Alaska. The total reserves of the Persian Gulf region (Kuwait, Saudi Arabia, etc.) are estimated at 355 billion barrels. The estimate (by the same methods) for Alaska is 200 billion barrels. These are not proven reserves but the estimated recoverable reserves. Thus it is clear that the Alaskan reserves are certainly in the same class as the Persian Gulf reserves with respect to magnitude recoverable.

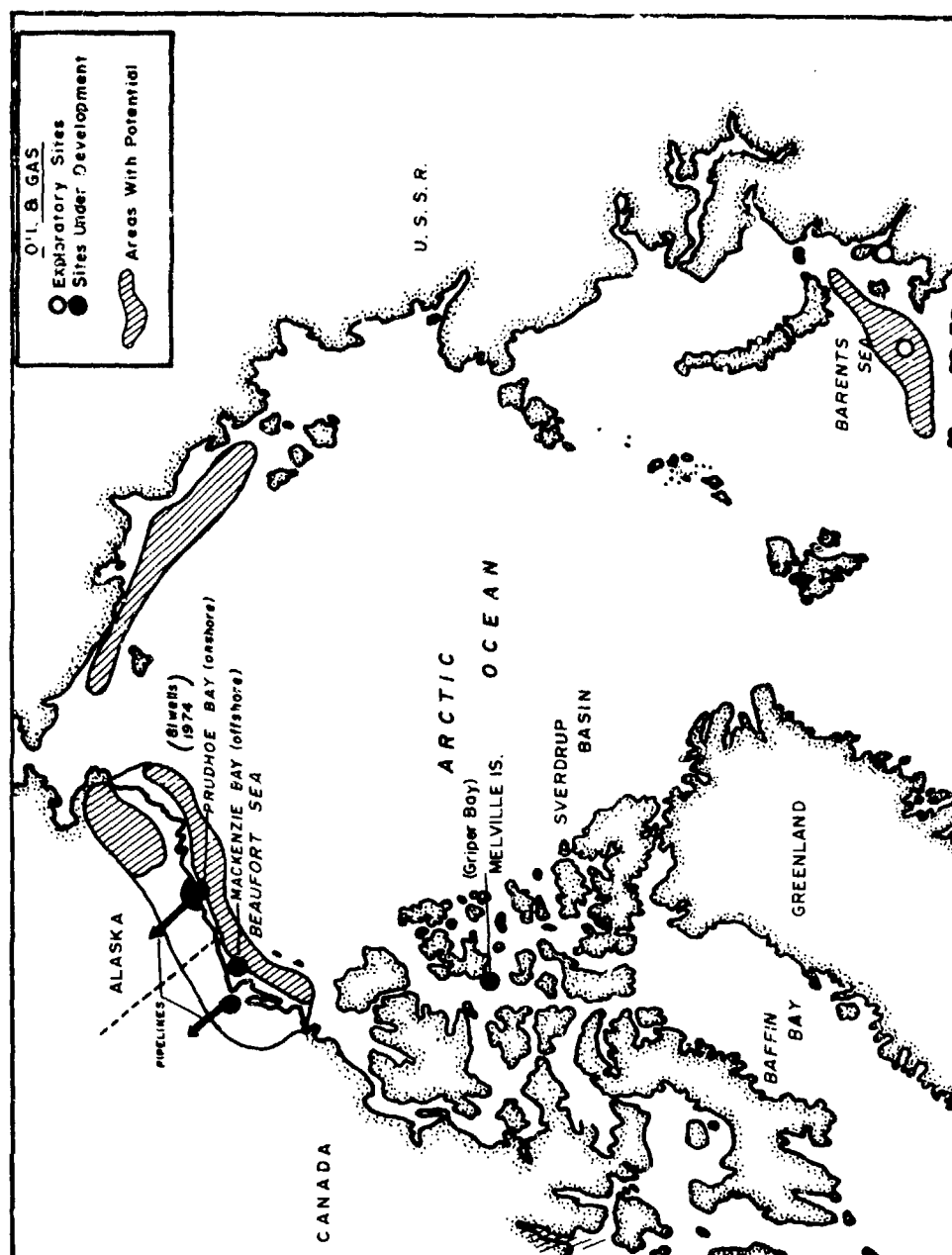


FIGURE 1.

LOCATION MAP FOR OIL AND GAS EXPLORATION AND DEVELOPMENT

Figure 2 shows the known and predicted crude oil production and consumption for the world and the U. S. This is a very general graph, not meant to be used for detailed determination. The predicted portions are just that, predicted; they probably do not show the most accurate slopes (change of rate) nor do they show the least accurate slopes. One thing that is clear regardless of the various cautions necessary when interpreting Figure 2 is that U. S. consumption will exceed U. S. production. This will most certainly result in increased maritime activity in the Western Arctic.

More specific to Alaska is the contents of Table 1.

TABLE 1
PROJECTED AND KNOWN QUANTITY OF OIL REQUIRED BY THE U.S. AND
AVAILABLE FROM ALASKAN RESERVES

CARGO OIL	U.S. DEMAND (per year)	ALASKAN RESOURCE (total)
Year	Barrels	Metric Tons
1973	6.31×10^9	9.02×10^8
1985	8.61×10^9	12.30×10^8
2000	11.44×10^9	16.34×10^8

It is clear that the Alaskan reserves are great but may not be sufficient. If we determine the total U. S. consumption from Figure 2 for the years 1977 to 2000, we will have an estimate of the total oil used from 1977 to 2000. The same thing can be done for the production curve. Then by subtracting the production from consumption, an estimate of the deficit is obtained. The deficit must be satisfied by imports, discovery and exploitation and/or reduction of consumption between 1977 and 2000. The figures are shown in Table 2.

TABLE 2
U.S. OIL PRODUCTION AND CONSUMPTION
1977 to 2000

Total amount consumed	2.134×10^{10} barrels
Total U.S. production	1.556×10^{11} barrels
Consumption less production	5.78×10^{10} barrels

The amount consumed as shown in Table 2 (2.134×10^{11} bbls) is 1.34×10^{10} bbls more oil than the estimated total Alaskan reserve (from Table 1). Table 3 shows the projected quantity of oil resources to be transported by ship from the Western Arctic from the year 1978 to the year 2000.

Two sizes of vessels have been proposed to transport the Arctic oil. They are 125,000 DWT and 250,000 DWT. The 125,000 DWT icebreaking oil tanker would carry approximately 875,000 bbls of crude oil. The smaller vessel would draw 54 feet of water. The 250,000 DWT vessel would carry 1,750,000 bbls of crude oil and draw 68 feet of water. The draft is mentioned because of the restrictions it imposes on routes and harbor/docking facilities.

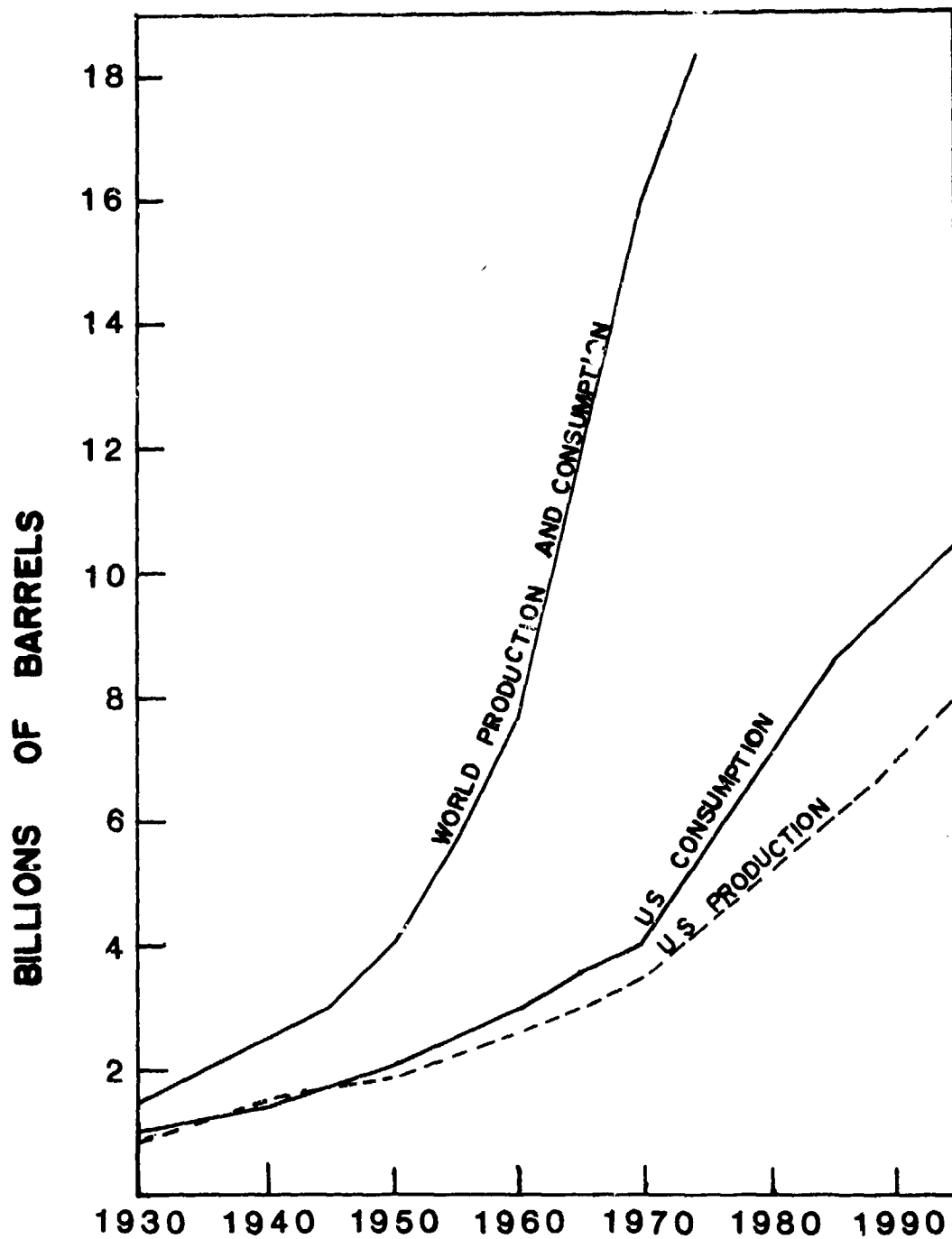


FIGURE 2

CRUDE OIL PRODUCTION AND CONSUMPTION KNOWN AND PROJECTED (VARIOUS SOURCES)

TABLE 3

PROJECTED QUANTITY OF OIL TO BE TRANSPORTED OUT OF THE WESTERN ARCTIC BETWEEN 1978 and 2000

	1978 to 1980	1981 to 1985	1986 to 1990	1991 to 1995	1996 to 2000
METRIC TONS	7.25 x 10 ⁶ to 54.43 x 10 ⁶	54.43 x 10 ⁶ to 163.29 x 10 ⁶	163.29 x 10 ⁶ to 181.44 x 10 ⁶	181.44 x 10 ⁶ to 249.48 x 10 ⁶	249.48 x 10 ⁶
BARRELS	50.7 x 10 ⁶ to 3.8 x 10 ⁸	3.8 x 10 ⁸ to 1.14 x 10 ⁹	1.14 x 10 ⁹ to 1.27 x 10 ⁹	1.27 x 10 ⁹ to 1.74 x 10 ⁹	1.74 x 10 ⁹

The cost of these icebreaking oil tankers is estimated at \$90 million and \$150 million, respectively. Approximately three years would be required to build one. Thus, if construction began in 1978, the first icebreaking tanker would be ready for service in 1981. By 1981 the plan is for the Alaskan pipeline to move 2×10^6 bbls of oil per day (BOD) or 7.3×10^8 bbls per year (BOY). At the rate of 7.3×10^8 BOY, it would take 274 years to move the estimated 2.0×10^{11} bbls of oil out of Alaska. U. S. consumption is projected to be 7×10^9 BOY by 1980. Thus the quantity of oil delivered by the pipeline is approximately one-tenth of the total estimated annual U. S. consumption for 1980. The remaining nine-tenths will have to come from other domestic production and imports. A very small fraction of the nine-tenths will be available from other domestic sources so the majority will come from imports. This will not be energy independence or even close.

The total transported (using numbers from Table 3) will be about 2.66×10^{10} barrels for the period 1978 to 2000. This is approximately (one-eighth) twelve percent of the total Alaskan reserve. Combining the projected ship (2.6×10^{10}) quantities with the pipeline (1.5×10^{10}) quantities (4.11×10^{10}) one-fifth or twenty percent of the total Alaskan reserve will be used by the year 2000. Approximately twenty percent of the total U. S. consumption will have been met by the Alaskan reserves. These figures become important for political reasons. If the Federal Government promotes an all-out effort to be self-sufficient in petroleum, then it is abundantly clear that more oil will have to be transported from Alaska. The present Federal energy "policies" stress increased production. Thus petroleum will remain a primary source of energy until exhausted. The interim will probably be characterized by increased emphasis on development of Alaskan oil and gas reserves. Another pipeline is probable as well as Liquid Natural Gas (LNG) traffic in Arctic waters.

3.5 Vessel Traffic Density

The number of vessels will not increase appreciably until 1980. This is because of the necessary lead time required to construct specialized ships, i.e., icebreaking oil tankers. Many alternatives are possible from tug barge (Arctic Challenger) combinations to the behemoth 250,000 DWT icebreaking tankers.

The alternative or alternatives chosen will depend on many factors. Principal among these factors is potential return on investment. For example, construction of a 125,000 DWT icebreaking tanker which will carry 875,000 bbls of oil per trip would cost about \$90 million. If the oil brought \$12 per bbl then each trip would gross \$10,500,000. Of course, this is the gross figure and not the net per trip. Some estimates developed for the Alaskan pipeline gave the transportation cost at a rate of 2×10^6 BOD of approximately \$1.00 per bbl. The estimate provided for an icebreaking tanker system is \$.59 per bbl. These are estimates not facts. The tanker estimate is for a 250,000 DWT vessel from Prudhoe Bay to Unimak. The pipeline is from Prudhoe Bay to Valdez. In both cases, transshipment is required.

Additionally, the tanker estimate includes the annual costs for manning, fuel, capital amortization, insurance, maintenance, repair and miscellaneous for a 350-day operating year. Thus the margin per trip is \$9,983,750

to cover profit, production, storage, terminal, refining and distribution costs. The per bbl cost estimated for a 2×10^5 BOD throughput with 250,000 DWT's including tanker and terminal related costs is \$.77. This results in a margin of \$9,826,250 per trip. It is clear that the potential for an excellent return on investment is high.

3.6 Fleet Size Required

Because the precise bathymetry of the probable Arctic vessel routes is unknown, the early fleet would most likely be 125,000 DWT with a draft of 54 feet fully loaded. Various bases for estimation of the number of vessels needed are possible but only two will be used.

3.7 Basis of Estimation

First is an estimate based on an assumed parity throughput with the pipeline (2×10^5 BOD). It would result in a doubling of Alaskan oil reserves delivered annually for domestic use. Still not enough for domestic supplied energy independence.

The number of ships is determined for delivery of 2×10^6 BOD over a 350-day operating year. This amounts to 7.3×10^8 barrels per year delivered to Unimak. Using 125,000 DWT to move 7.3×10^8 barrels would require 28 ships to make 30 round trips each per 350-day operational year. Each round trip would require about 11.5 days for the route Prudhoe Bay-Unimak. Depending on bathymetry and solution of potential loading and maneuvering problems at terminals, the number of ships could be reduced. The reduction using 250,000 DWT vessels would be from 28 to 14.

The second basis of estimation assumes that politics will dictate total dependence on Alaskan crude oil for the total U. S. supply. This is not a very reasonable alternative, however it provides a useful exercise because it describes an extreme or worst case situation which would have a devastating impact on presently planned levels of Coast Guard resources.

It is clear here at the very outset that a large fleet would be required and also that all of the estimated Alaskan recoverable reserves would be exhausted before the year 2000.

The 1981 fleet would have to be essentially all 250,000 DWT vessels and would have to move 7.4×10^9 BOY (projected U.S. consumption for 1981) less 7.3×10^8 for the pipeline. To move 6.67×10^9 BOY with 250,000 DWT would take 3812 (3811.43) trips with about 1,750,000 bbls per ship. Each trip would require 11.5 days out of a 350-day operating year. This means that one ship could make 30 trips per year. Thus 128 (127.05) ships (plus the pipeline) would be required to meet the 1981 U.S. consumption. Of course the 128 ships would not be built simultaneously and would not be available in 1981, but an accelerated schedule would be politically desirable. Using all capable shipyards could result in 10 ships per year beginning in 1981. If the first 10 ships saw full service for the whole year of 1981 then 5.25×10^8 bbls of oil would be transported in addition to the 7.3×10^8 bbls transported by the pipeline. The U.S. consumption projected for 1981 is 7.4×10^9 bbls. By subtraction the deficit (7.4×10^9 minus 1.255×10^9) is 6.145×10^9 bbls. With the continued addition of 10 ships per year approximately 1.9805×10^{10} bbls would be the total transported by 1987 (including the pipeline transported oil). By 1988 transported Alaskan oil including one pipeline

and eighty (80) 250,000 DWT's would be 4.93×10^9 bbls or 4.67×10^9 bbls short of the 1981 demand. Without beating this to death, one more thing will be considered. When will all the Alaskan oil be used up at the maximum transport rate possible? Adding 10 ships per year is considered, in combination with the pipeline, to be the maximum transport capacity. The total Alaskan reserve (recoverable) is put at 2×10^{11} bbls. Using Figure 3, the total transported by ship (adding 10 more ships per year) can be determined. The reserve would be exhausted by 1996. One hundred sixty ships could be in service by that time. Of course the purpose of working out this alternative was to show a worst case situation. The impact on Coast Guard operations would be tremendous especially in the vessel traffic control, marine inspection, icebreaking services (escort), search and rescue, aids to navigation and marine environmental protection areas.

3.8 Liquified Natural Gas

The second most important cargo will be gas, specifically in a liquified state. Unfortunately the pack ice constitutes a major impediment to conventionally designed and built LNG carriers. However, the estimated reserves, although only one-third the projected total U. S. demand to the year 2000, are completely adequate to justify the design and construction of icebreaking LNG carriers. A major shipbuilder has proposed this type of vessel for development of the Canadian Melville Island gas discovery which is estimated at 280 billion cubic meters or about one-thirtieth the estimated Alaskan gas reserves. The Canadian government (part owner) petroleum company has initiated a \$1 billion pilot project to provide Melville Island gas to eastern Canadian markets. Included in the project are plans to complete a subsea well, flow line and gathering network, a liquefaction plant and two LNG carriers. The carriers are to be designed as double hulled, 150,000 hp with 125,000 cubic meter capacity and capable of moving through ice seven feet thick at constant speed. The pilot operation is expected to be on line by early 1982.

The Canadian LNG carrier project is independent of any decision to build a pipeline to carry Mackenzie Delta and Prudhoe Bay gas (recently agreed to by U. S. and Canada). It is clear, considering the projected U. S. demand for natural gas (Table 4) and the estimated Alaskan reserves (Table 4), that LNG carriers will be used for transport of Alaskan gas. The Canadians estimate that the Melville Island reserves will justify construction of five icebreaking LNG carriers. Of course this does not mean that the Alaskan gas reserves would justify thirty times or 150 icebreaking LNG carriers but it does provide for incentive and a somewhat objective basis for speculation. There will surely be some industrial movement in the direction of specialized LNG carriers probably in the range of 5 to 10 vessels over the next 25 years. Table 5 shows a projection of the quantity of LNG to be moved by ship from the western Arctic between 1981 and 2000.

3.9 Other Cargoes

Because of limited time the same detailed discussion as given for petroleum will not be given for the other resources. Rather some descriptive information is provided in Tables 4 and 5. Oil and gas are included in these tables only for reference. The reader can infer the consequences of exploitation of these other resources and can immediately conclude that an increase in commercial marine vessel traffic is inevitable in the Western Arctic. Table 5A shows the projected number of ships (by size) required to transport the quantities shown in Table 5.

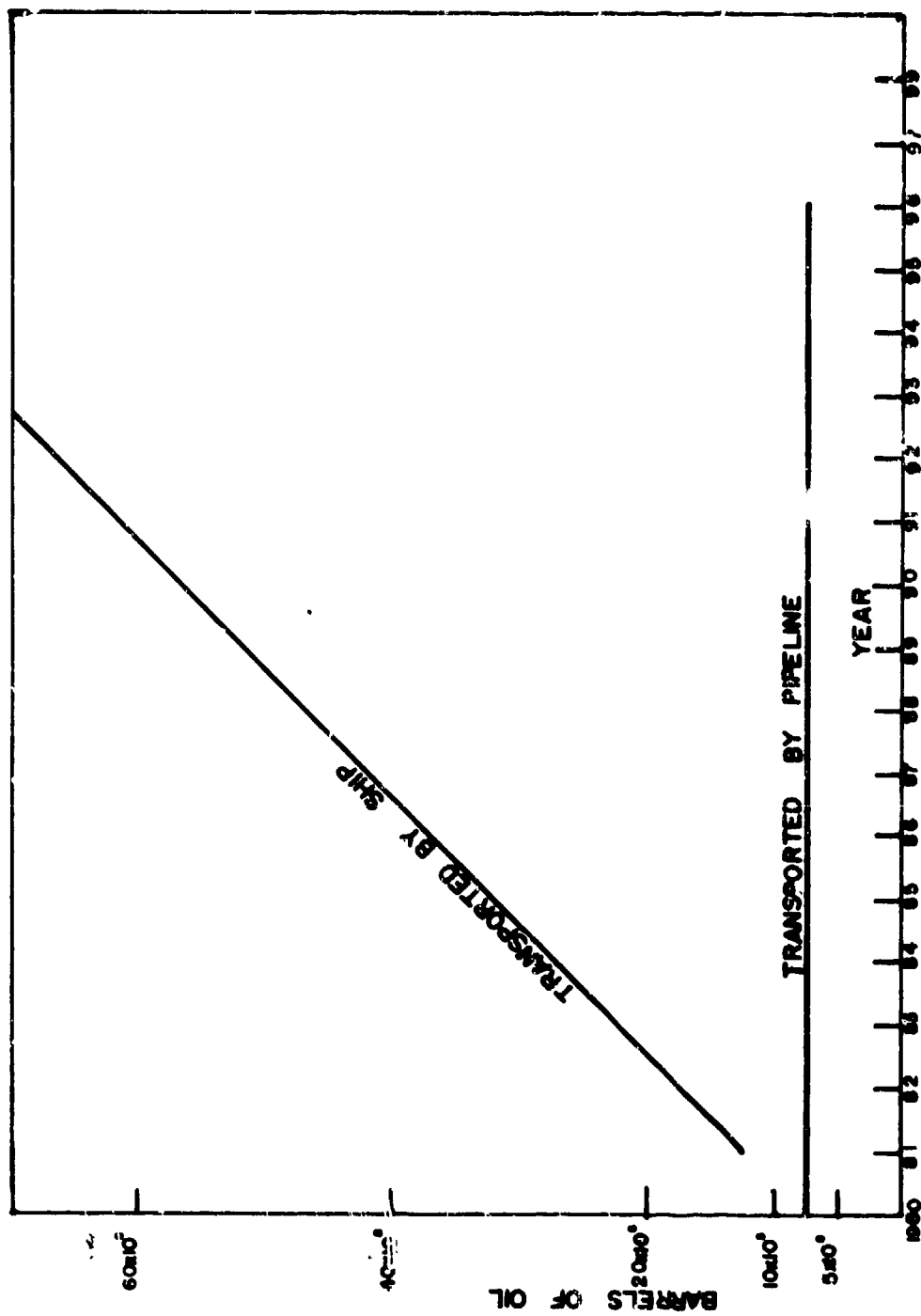


FIGURE 3
 QUANTITY OF CRUDE OIL TRANSPORTED BY ADDING TEN
 250,000 DWT ICEBREAKING TANKERS PER YEAR AND THE PIPELINE

TABLE 4
KNOWN AND PROJECTED DEMAND AND ESTIMATED RESOURCE TOTAL

CARGO		U.S. DEMAND	ALASKA RESOURCE TOTAL
<u>OIL</u>			
<u>YEAR</u>	<u>MILLION BARRELS</u>	<u>METRIC TONS</u>	2.85×10^{10} metric tons
1973	6,317	9.02×10^8	
1985	8,610	12.30×10^8	
2000	11,442	16.34×10^8	200×10^9 bbls.
<u>GAS</u>			
<u>YEAR</u>		<u>CUBIC METERS</u>	$8.49 \times 10^{12} \text{ m}^3$
1973		$7.08 \times 10^{11} \text{ m}^3$	
1985		$9.34 \times 10^{11} \text{ m}^3$	
2000		$1.24 \times 10^{12} \text{ m}^3$	
<u>COAL</u>			
<u>YEAR</u>		<u>MILLION METRIC TONS</u>	181 billion metric tons
1973		509.85	
1985		607.82	
2000		861.84	
<u>COPPER</u>			
<u>YEAR</u>		<u>THOUSAND METRIC TONS</u>	100 million metric tons of 1.3% ore
1973		1476.01	
1985		2630.88	
2000		4898.88	
<u>FLUORITE</u>			
<u>YEAR</u>		<u>THOUSAND METRIC TONS</u>	28 million metric tons of 18% CaF_2
1973		2358.72	
1985		4399.92	
2000		8799.84	
<u>TIN & TUNGSTEN</u>			
<u>YEAR</u>		<u>THOUSAND METRIC TONS</u>	unknown
1973		50.7	
1985		71.12	
2000		91.45	
<u>GRAPHITE</u>			
<u>YEAR</u>		<u>THOUSAND METRIC TONS</u>	1 million metric tons
1973		51.71	
1985		63.5	
2000		86.18	

TABLE 5

PROJECTED SHIP CARGOS BY QUANTITY FROM THE WESTERN ARCTIC FOR 1978 TO 2000
(THOUSAND METRIC TONS PER YEAR, EXCEPT LNG WHICH IS IN CUBIC METERS)

CARGO	1978-1980	1981-1985	1986-1990	1991-1995	1996-2000
OIL	7,257.6 to 54,432	54,432 to 163,296	163,296 to 181,440	181,440 to 249,480	249,480
GAS LNG in cubic meters	0	125,000 m ³ to 375,000 m ³	500,000 m ³ to 750,000 m ³	750,000 m ³ to 1,250,000 m ³	1,250,000 m ³
COAL	0	3,175.2	3,175.2	3,175.2	3,175.2
COPPER	0	199.58	294.84	294.84	294.84
FLUORITE	0	272.16	272.16	272.16	272.16
TIN & TUNGSTEN	0	8.16	8.62	8.62	17.24
GRAPHITE	0	0	32.72	2.72	2.72
MERCURY & ANTIMONY	0	.91	1.81	1.81	1.81

TABLE 5A
PROJECTED NUMBER OF SHIPS (BY SIZE) REQUIRED TO TRANSPORT QUANTITY OF CARGOS SHOWN
IN TABLE 5 FOR 1978 TO 2000

CARGO	1978-1980	1981-1985	1986-1990	1991-1995	1996-2000
* OIL 250,000 DWT	7	22	25	34	34
* GAS (LNG) 125x10 ³ CU. M. CAPACITY	0	1	5	10	10
COAL 60,000 DWT	0	3	3	3	3
COPPER 35,000 DWT	0	2	3	4	4
FLUORITE 35,000 DWT	0	2	2	2	2
TIN & TUNGSTEN 35,000 DWT	0	1	1	1	2
GRAPHITE 35,000 DWT	0	0	1	1	0
MERCURY & ANTIMONY 35,000 DWT	0	1	1	1	1
TOTALS	7	32	41	56	56

* ASSUMES 30 TRIPS (11.5 DAYS EACH) PER YEAR PER VESSEL.

3.10 Timing

Timing of the developments of the various commodities such as the mineral ores will be different than for oil and gas. Specifically, oil and gas will be essentially developed by geographic regions whereas the ore minerals will be developed on a local geographic basis. The ore minerals will be much more subject to local conditions when determinations are made to develop one deposit or another. Timing will be much different for developing the ore minerals. This is because overall economic activity in the Western Arctic will be paced by the oil and gas industries. In general, the exploitation of the oil and gas will result in the following: improved transportation, improved communications facilities, increased knowledge of unique-to-the-north operational problems, greater availability of labor, larger sources of capital investment funds and increased demand by industry. These work together to speed up mineral development. Actually the timing differences can be summed up as follows: ore minerals will be developed after oil and gas developments are well on the way.

Scheduling is an integral part of planning and especially important when long lead times are required. It takes a few years to design and construct an icebreaking LNG carrier. To set the stage a projection of which regions will begin production, when and the estimated quantity is presented for oil in Table 6. Cook Inlet is not included in Table 2 because it is already in production.

The North Slope region is naturally the earliest to go into production. Transportation is in the beginning primarily by the Alyeska pipeline. Unfortunately with quantities ranging from zero to about 200,000 barrels per day until 1979 to 1980, the amount of transport will not meet demand as shown in Section 3.7. The demand will probably be met by either icebreaking 250,000 DWT tankers or special tug-barge combinations. Because of the lead times required and experience, the tug-barge combinations will most likely be used first.

3.11 General Summary for Cargoes

It has been assumed that the Alyeska pipeline will routinely transport 2×10^6 BOD and that a second pipeline (Mackenzie Valley) will carry gas and be operating by 1982. It is further assumed that workable settlements of the Alaskan Native Claims Act will be forthcoming. The present situation where land ownership or rights to develop are unclear is not conducive to capital investment for exploitation especially of minerals. From Table 5 it is clear that all the U. S. demand through the year 2000 cannot be met by the estimated Alaskan reserves. This of course does not mean that the Alaskan resources will not be exploited. It only suggests that other sources or some reduction in demand will be necessary if all U. S. demands particularly for oil are to be met from domestic sources. Caution is in order because these are projections, not facts. For example, the estimated quantity of oil reserves will justify planning for twenty to twenty-five years of increasing marine traffic in the Western Arctic and therefore increasing demand for Coast Guard services.

The reserves and demand for natural gas (Table 5) present some very intricate problems. The demand for natural gas for the 25-year period to 2000 is approximately 24×10^{12} cubic meters. This is roughly three times the

TABLE 6
PROJECTED OIL PRODUCTION REGIONS AND WHEN MAJOR PRODUCTION BEGINS

PRODUCTION REGION	ESTIMATED QUANTITY RECOVERABLE (25% of Total est reserves)	WHEN
NORTH SLOPE	50×10^9 bbls.	1978
GULF OF AK	20×10^9 bbls.	1983
BRISTOL BAY	4×10^9 bbls.	1986
BERING SEA SHELF	90×10^9 bbls.	1990
ARCTIC OCEAN SHELF	5×10^9 bbls.	2000

estimated 8.5×10^{12} cubic meter reserve. The alternatives for transport of natural gas are essentially pipeline and specialized tanker ships (LNG carriers).

The Canadians have already started a \$1 billion pilot project to bring Arctic Island's natural gas to eastern Canadian markets.

3.12 Vessel Routes

Figures 4 and 5 show the most probable routes for marine transport of oil and other cargoes, respectively. Many considerations go into the selection of a route. Basically, two levels of detail are required for both time and space (geography). The two for time are long-term (seasonal) and near real time (on scene). The space or geography concerns the general whole Arctic region and the immediate within 50 miles of the expected position of a vessel.

Other considerations are bathymetry, pressure ridges, ice thickness, ice concentration, icing potential, and along-route weather. These concern essentially environmental parameters over which man has little or no control.

Bathymetry has been mentioned before. The major problem is that precise water depth information is just not available for all of the western Arctic. This problem will be resolved, but for now the bathymetric charts just do not have the precision and detail required.

Pressure ridges are the greatest impediment to marine shipping in the ice covered waters of the western Arctic. Pressure ridges are the result of deformation of the ice cover. They are grouped into two main categories: (1) compressional, and (2) shear. This categorization is based on their mode of origin. Ridges from either category can be formidable obstacles to navigation.

Pressure ridges arising from the collision of floes are made up of blocks of ice which are the same thickness as the colliding floes. Often a large ice floe will break and form two floes with a lane of open water (a lead) between them. Then, depending on temperature, ice will form in the lead. When the floes are moved together mainly by the wind (current is often a factor, alone or in combination with the wind) a pressure ridge will form where the two edges meet. Immediately after a ridge has formed it will contain distinctly individual ice fragments, with water and slush in the voids (the presence of slush or ice crystals depends on the temperature). When the ridge has aged the ice fragments will be less distinguishable and most if not all the water will have drained or frozen in place to fill the voids. The aged pressure ridge is a most formidable obstacle, essentially impenetrable by all but the most powerful ships.

The height (sail), width, depth of keel, unbroken length of the ridge, total ice field pressure and depth and distribution of snow cover are the pertinent characteristics in addition to age and frequency of ridges per km along the vessel's track. Because pressure ridges are such formidable barriers, information about them is very important for ship routing.

The frequency and sail height of pressure ridges might provide a useful index for determining the relative difficulty of transit for any given route. This type of information is not presently available for any of the routes shown in Figures 4 or 5. However, some information for the near shore areas in the Beaufort and Chukchi Seas does exist (Weeks, et al., 1977). Figures 6 and 7 show composites of ridge frequency per 100 km versus ridge

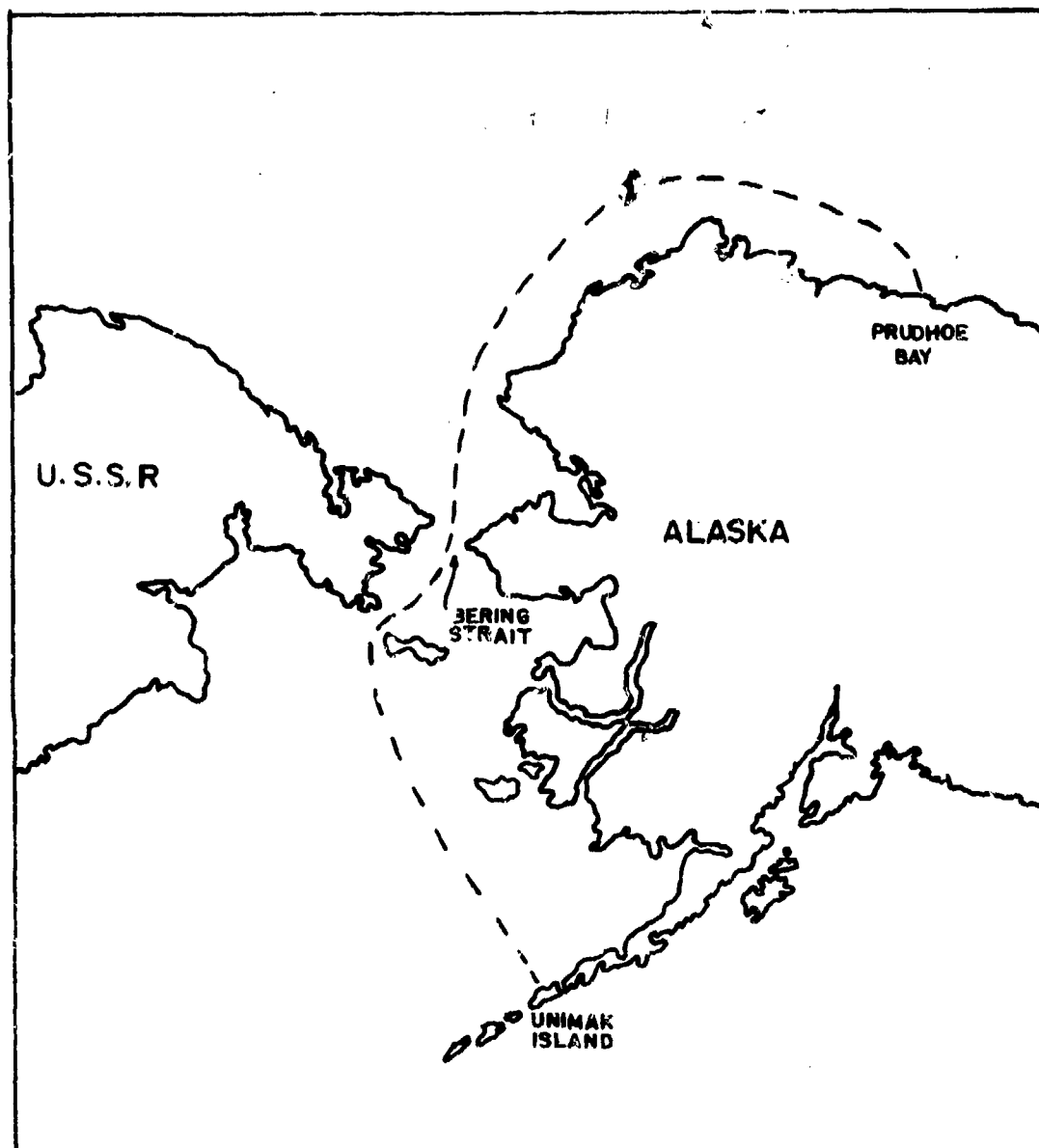


FIGURE 4

MOST PROBABLE ROUTE FOR MARINE TRANSPORT OF OIL

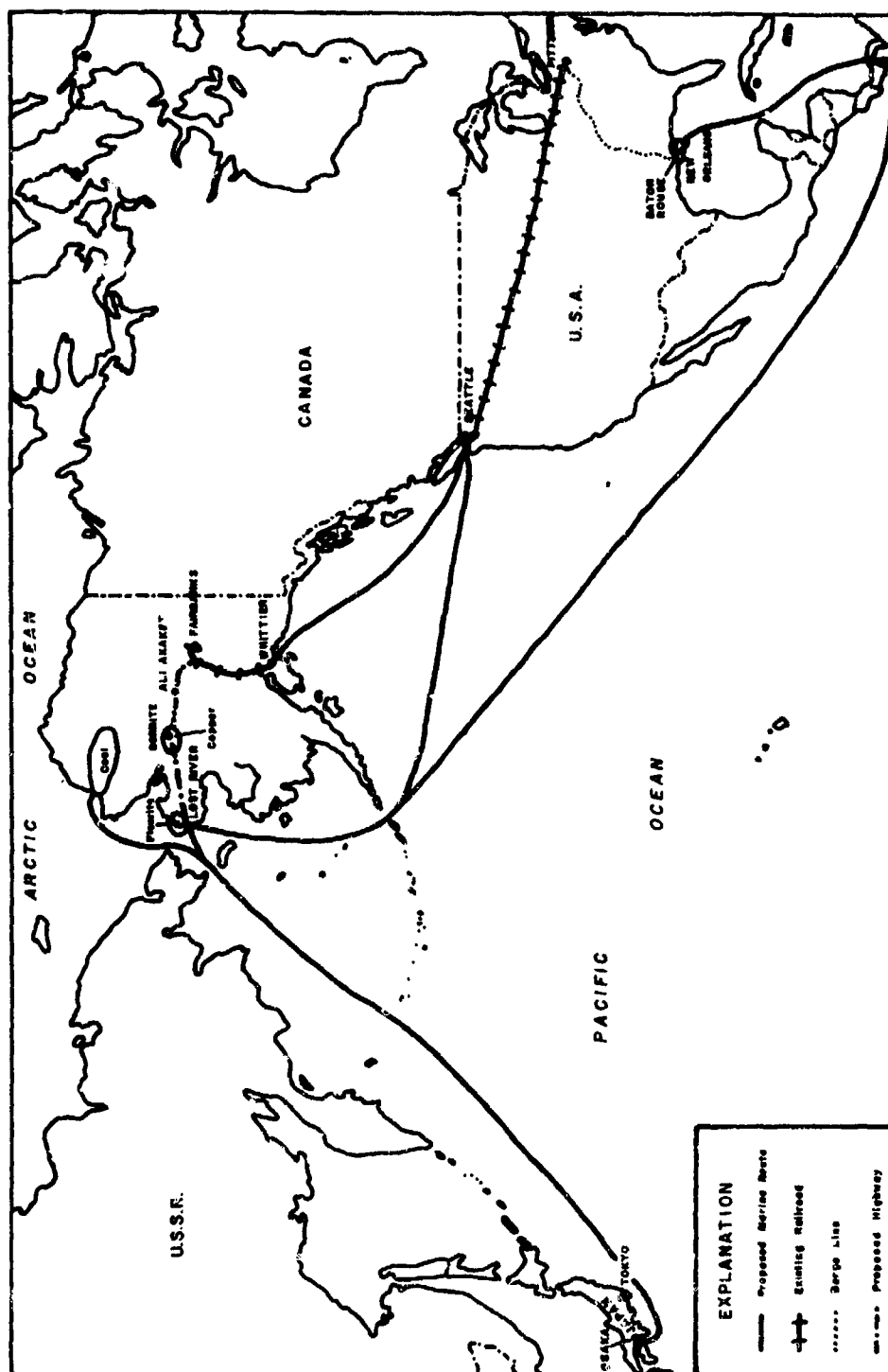


FIGURE 5
ALTERNATIVE ROUTES FOR VARIOUS CARGOES, PETROLEUM NOT SHOWN

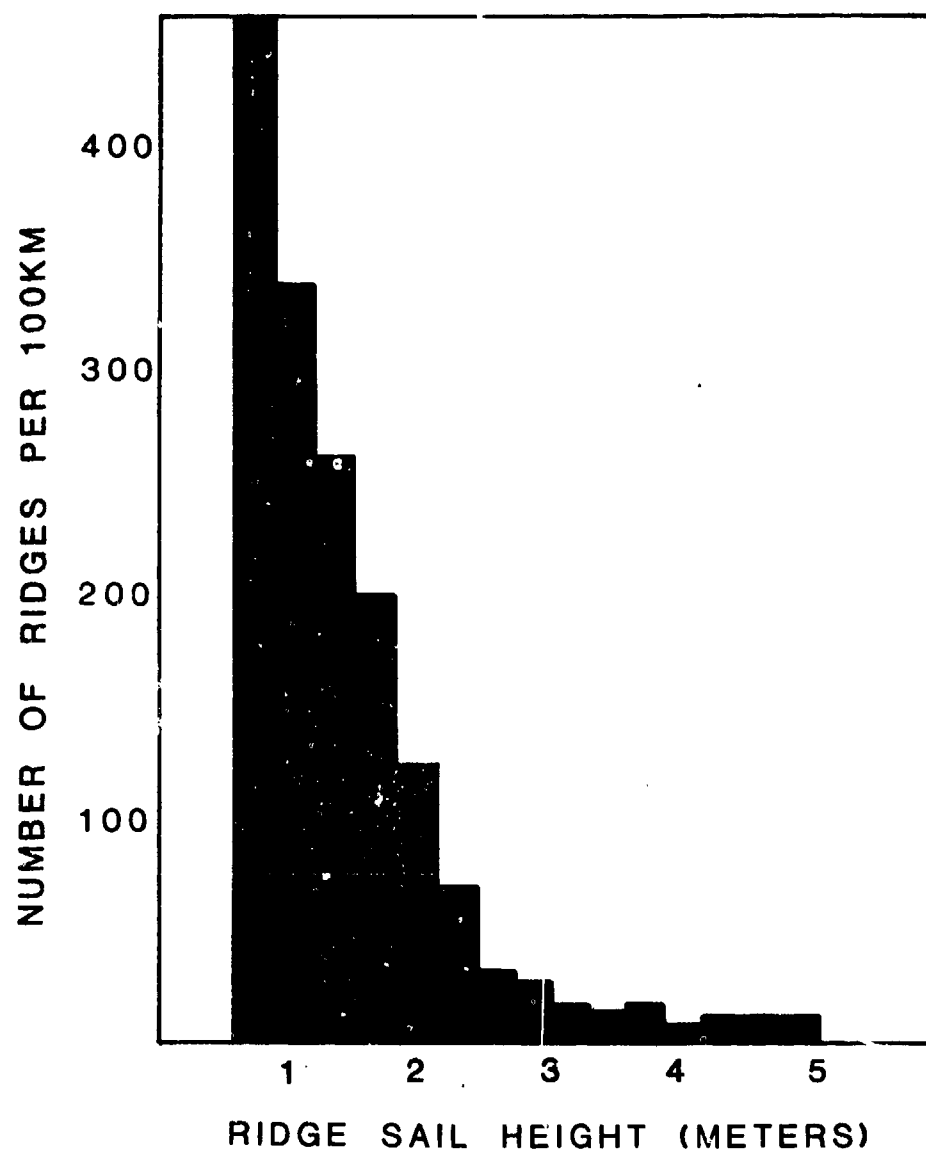


FIGURE 6

RIDGE SAIL HEIGHT VERSUS NUMBER OF RIDGES
PER 100KM FOR NEAR SHORE CHUKCHI SEA

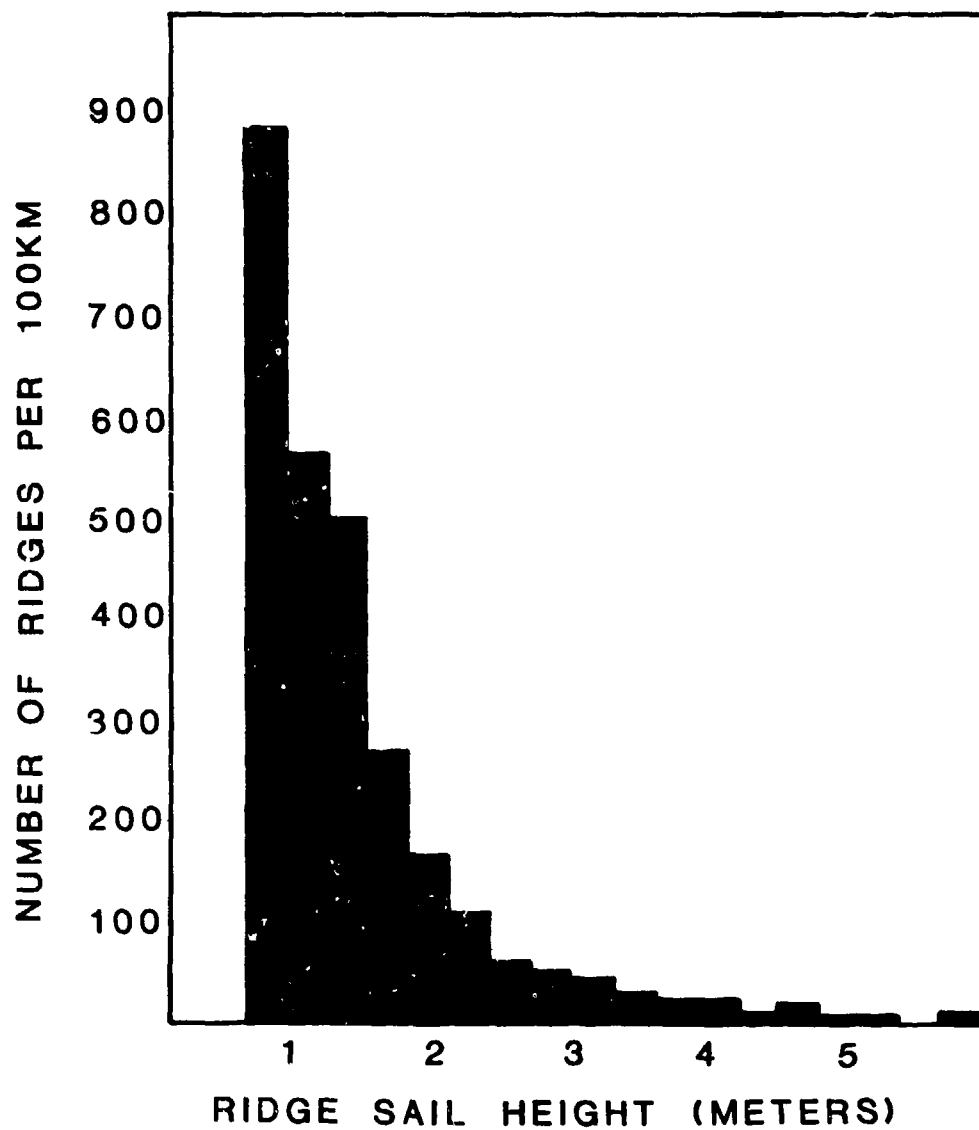


FIGURE 7
RIDGE SAIL HEIGHT VERSUS NUMBER OF RIDGES
PER 100KM FOR NEAR SHORE BEAUFORT SEA

sail height for the Beaufort and Chukchi Seas (near shore areas), respectively. These are censored distributions; that is the lower bound is approximately 1 meter, thus all pressure ridges are not reported. The distributions are skewed; that is they are not symmetrical, thus descriptive statistics like the arithmetic mean or standard deviation are not appropriate and should not be used. It is clear by examination that the major proportion of near-shore pressure ridges are less than 2 meters in height. Figure 8 shows a similar histogram for a Beaufort Sea offshore area. Again the asymmetry is strongly shown. The majority of the ridge sail heights seem to be less than 2 meters.

Ice thickness and ice concentration are the next most important characteristics that can affect ship transit. Various presentations are possible to depict the status of the ice in very general terms. For the purposes of this study, Figure 9 shows a chart of the vessel control zones along the Prudhoe Bay to Unimak Island (Figure 4) route. This is the potential oil tanker route. Routes shown in Figure 5 will have less ice over their total distance to contend with. Tables 7 and 8 summarize ice information for this route (Figure 4) for March (extreme) and September (minimum) conditions.

4.0 VESSEL ROUTING SYSTEMS

Vessel routing is not a new concept. M. F. MAURY carefully collected observations from ship logbooks and in 1852 used this information to recommend routes for crossing the Atlantic. He considered avoidance of collisions as the major benefit. MAURY's work was the precursor of the present Navy Hydrographic Office Pilot Charts. "Ocean Passages," published by the British Admiralty, serves the same purpose.

The above two publications use climatological patterns as the basis for routing.

Formalized routing systems were first used in the United States in the early 1950's. These systems were essentially meteorological advisory services provided from shore to the ships at sea. The same ideas were adopted by many European countries in the 1960's.

In general the systems provide, via a group of mariners that have extensive experience at sea, the most advantageous routes considering all past and up-to-the-minute information. The advisors have at hand a continuous flow of analysis and forecast charts, warnings, bulletins, ice information and satellite pictures. With this wealth of information and an armada of electronic communications devices the advisors select the best routes for the users of the system.

Detailed descriptions of the methods used, the variables considered and the communications formats are beyond the present study. For our purposes a more detailed look at what an ice information system is and how it is used for routing vessels is more appropriate.

4.1 Ice Information Systems

Systematic accumulation, analysis and dissemination of ice information is not a new idea; however, operational centers for the purpose are not common.

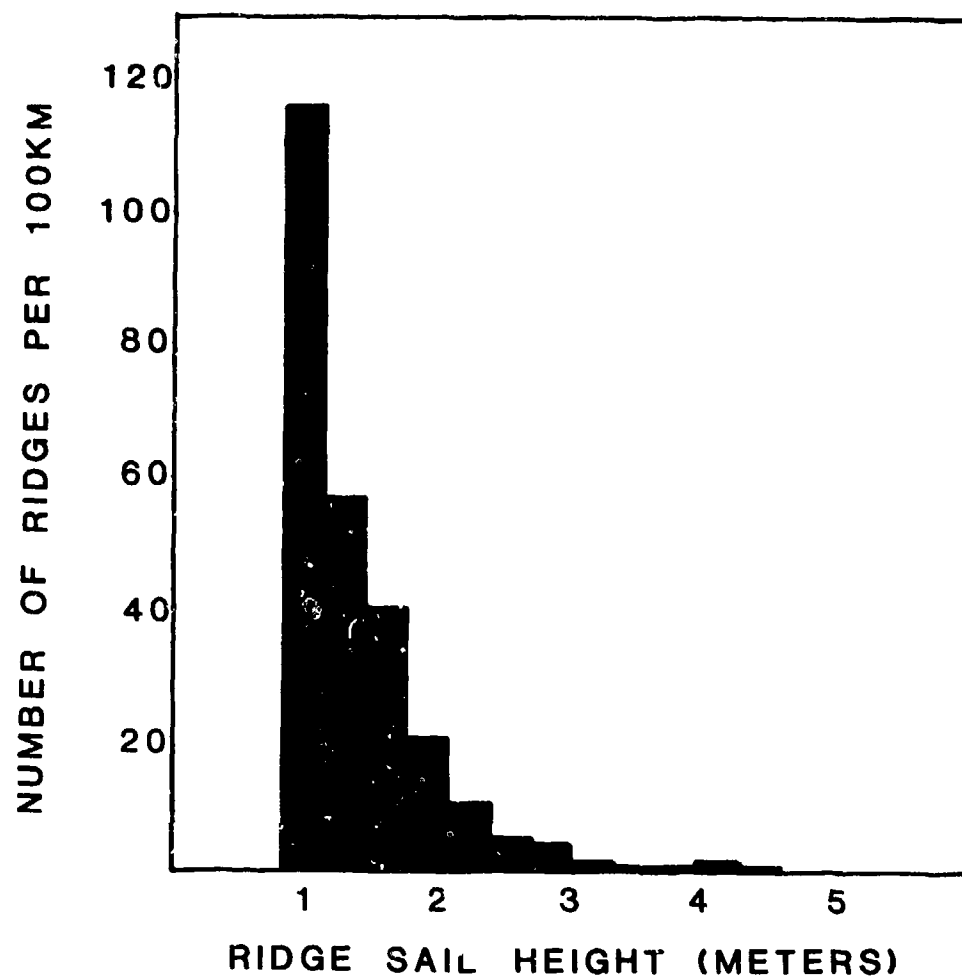


FIGURE 8

RIDGE SAIL HEIGHT VERSUS NUMBER OF RIDGES
PER 100KM FOR OFFSHORE BEAUFORT SEA

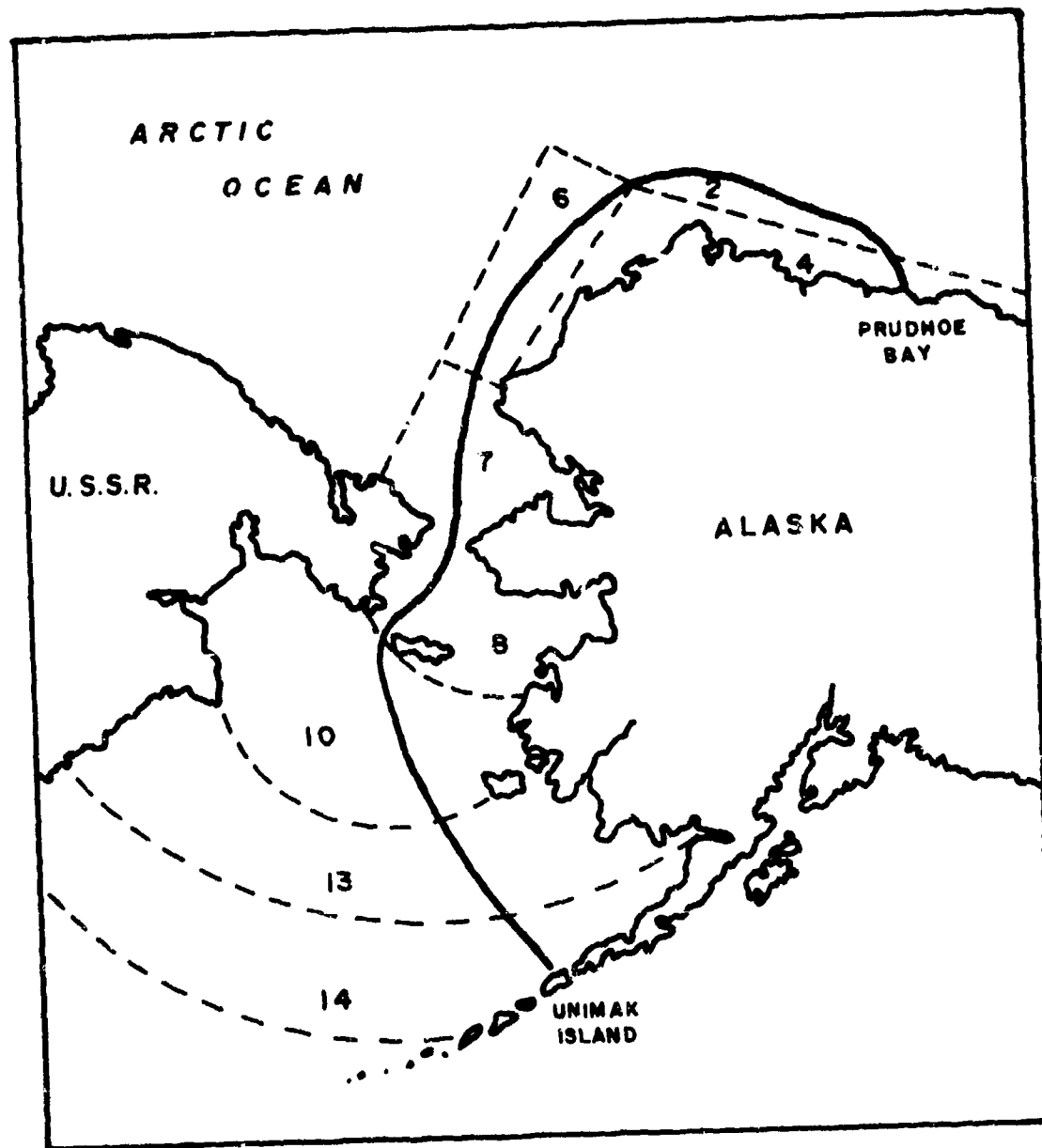


FIGURE 9

ICE INFORMATION ZONES FOR PRUDHOE BAY TO UNIMAK ISLAND OIL TANKER ROUTE

TABLE 7

MARCH ICE INFORMATION FOR PRUDHOE BAY TO UNIMAK ISLAND SHIP ROUTE

Zone (from fig. 9)	Ship Route Distance Km	1st Year Ice Thick (cm)	Multi. Year Ice Thick (cm)	Ratio 1st Yr/ Multi. Yr.	Concentration (octas)	Pressure Ridge freq/Km
4	93	101	243	0.9	7	9
2	361	127	305	0.5	7	11
6	417	101	243	0.7	7	5
7	361	101	101	1.0	7	5
8	306	101	101	1.0	7	5
10	417	89	89	1.0	7	3
13	333	64	64	1.0	7	3
14	417	25	25	1.0	7	3

TABLE 2
SEPTEMBER ICE INFORMATION FOR PRUDHOE BAY TO UNIMAK ISLAND SHIP ROUTE

Zone (from fig. 9)	Ship Route Distance Km	1st Year Ice Thick (cm)	Multi. Year Ice Thick (cm)	Ratio 1st Yr/ Multi. Yr.	Concentration (octas)	Pressure Ridge freq/Km
4	93	12	168	0.5	1	1
2	361	25	229	0.5	1	5
6	417	12	168	0.5	1	1
7	361	12	12	1.0	1	1
8	306	8	8	1.0	1	< 1
10	417	5	5	1.0	1	< 1
13	333	2	2	1.0	1	< 1
14	417	2	2	1.0	1	< 1

The major impetus to develop and use an ice information system is, of course, economics, which generally translates into expanded Coast Guard activity. Descriptions of working systems are not prevalent in the literature. Examples are the Canadian and Swedish systems and the U.S. Coast Guard approach for the Great Lakes ice navigation season extension.

4.2 Canadian System

The Canadian system will be described in the following paragraphs. The Canadian Arctic is characterized by a cold climate, the consequence of which is sea ice formation over a large proportion of the marine areas. Sea ice is an impediment to ship transit.

During the summer the ice melts and breaks up so that essentially normal shipping is possible over large areas. Some areas are never effectively ice free even in summer. Thus, to promote safe shipping, information concerning the amount of ice present, the thickness, some measure of ship trafficability and how long the conditions will endure is needed.

To operate the system, data is required. The data is obtained from local observations by ships and from shore stations and aerial ice reconnaissance.

The aerial techniques are varied and rely on the use of an Electra aircraft. The aircraft is equipped with visual observing facilities, side-looking airborne radar, aerial cameras, airborne radiation thermometer, laser profilometer and an infrared line scanner. With the output from the above suite of sensors, the ice observer can prepare detailed charts that show ice coverage, distribution, age, floe size, estimated thickness, extent of ridging and extent of puddling. In addition to the observational data gathering sensors the aircraft is equipped with dual inertial navigation systems and dual Omega. Precise position is absolutely necessary for presentation of the data, especially in high latitudes.

Although not in full operational use at this time, the data received from earth orbiting satellites is expected to provide an increasingly more important input. The limitations of resolution and the frequency that areas are obscured by clouds and fog are presently the only drawbacks to more dependence on satellite systems for ice data collection. Future developments and refinements of and to satellite systems such as microwave radiometers, radar altimeters and synthetic aperture radar will bring increased utilization.

The major identified deficiency with the present Canadian ice reconnaissance program is the inability to obtain precise ice thickness information using remote sensors. Solutions are expected, but when is not known.

Using the above described program, the Canadian system then must prepare and transmit the information to the user.

Data transmission and distribution of the information is probably the weakest link in the present Canadian ice information system. There are many reasons why this is so and a few will be examined below. Sea ice is usually found in very complex patterns which are always difficult to describe in words or by brevity codes, particularly for small areas. Adding the characteristics of leads, thickness, age, field pressure, and ridging, it becomes clear that a pictorial method of data presentation is necessary. Presently facsimile

systems are used to transmit charts prepared by the ice observer and forecaster. This technique has worked well especially for tactical purposes. Of course the limits resulting from scale soon show up. This is because as the total area of coverage increases the amount of detail that can be included must decrease.

Various solutions to problems of transmission of detailed information have been sought. Satellite and SLAR sensors can provide extremely detailed imagery type ice information but the present facsimile equipment cannot reproduce it with sufficient fidelity. Photo facsimile techniques and digitization offer promise for an improved product.

Real or near real-time data acquisition and transmission is not yet a reality but is most desirable especially for ships already operating in the ice.

The next portion of the Canadian system concerns forecasting. For convenience it is divided into data processing for forecasting and data processing for climatological purposes.

The ice forecasting data processing is primarily done by hand, that is, it is not automated and performed with the aid of computers. The techniques rely on considerations of ocean temperatures and currents, present ice distributions and comparison with the "normal" ice distribution, and present and future weather conditions. Particular emphasis is placed on winds and heat transfer from the atmosphere to the earth's surface.

Processing of the data for the weather forecasting is essentially automated with computer implemented numerical methods for analysis and prognosis of meteorological charts.

Climatological data processing is becoming more important because the need is growing for more precise statistical knowledge of what are the "normal" ice conditions and what is the character of the departures from them. The climatological data is especially important for development of the Canadian north (the American north also) in particular for ship design, harbor development, pipeline construction and routing, etc.

Some complex problems encountered here are related to data storage, retrieval and presentation. For example, the concentration of ice by different types (first year, multi-year, etc.) can be shown very effectively in an Atlas. But it is also desirable to present information on the orientation, size and occurrence of pressure ridges. Here the immediate problem becomes one of developing a data storage and retrieval system that can handle various large (mega word) data banks at high transfer rates including direct processing of remotely sensed data and placing them in storage so that it can be accessed for many alternative presentation formats. This is obviously a complex computer system data handling problem. It is clear here that the Canadian system is moving toward a mix of atlases for regional small-scale (large area) data output and active retrieval by computer for more detailed large-scale (small area) information.

The basic ice service provided by the Canadian ice information system is to ships by time-sharing of high-powered radio facsimile broad-casts originating in Halifax and Edmonton. Regional radio facsimile services are provided during the summer shipping season from Frobisher and Resolute Bay. Gander, Newfoundland, also provides weather briefing services, as required, to the fishing industry. The coastal marine radio stations also provide scheduled plain language ice messages. During the year 1976 a public radio station in Newfoundland broadcast ice messages as a daily public service.

In addition to and supplementary to the Canadian information system is the Arctic Zones, Seasons and Ship classification system. This regulatory system is set out in the Canadian Government Arctic Shipping Pollution Prevention Regulations and the Shipping Safety Control Zones Order of 1974 and 1972, respectively.

These regulations are a giant step forward toward encouraging responsible transport system design while protecting the environment.

Briefly, these regulations provide a guide for indicating the maximum representative ice thickness for which a vessel must be designed for operation in various Arctic zones for the various seasons. Figure 10 is a summary of the Arctic ship class requirements from the regulations. This system is similar to the Swedish concept and has been used in Figure 9 and Tables 7 and 8 of this report.

4.3 Swedish System

The long sea coast of Sweden (similar in many ways to Alaska's) and the extensive network of inland waterways combined with the cold climate common to high northern latitudes result in moderate to severe marine transport problems. Sweden has been a seafaring nation since antiquity; thus by tradition and need they are very dependent on marine modes of transportation.

The dependence on marine transportation and the winter occurrence of ice in Swedish waters has encouraged the interest in developing a vessel routing system for ice-covered waters.

Essentially all vessel routing systems, especially for ice-covered waters, will consider the same list of data requirements and operational constraints.

In general the Swedish system considers the following: (1) degree of difficulty of winters, (2) ice reconnaissance and ice reporting, (3) ice-breaking service, (4) ship classification or ice class designations, (5) traffic regulations and traffic directives, (6) dates for application of when restrictions are in force, (7) requirements for ice class and tonnage size, and (8) winter navigation research.

The degree of difficulty of winters refers to the characterization of a winter as mild, normal or hard. More specifically they can summarize with statistics to show that about 25% are mild, 50% are normal and 25% are hard. The three "degrees" of winter are categorized on the positions of the maximum extent of ice. Also included in this criterion is an attempt to assess the relative contributions of general winter temperature conditions, the duration of below freezing temperatures, and the wind conditions that affect ice growth.

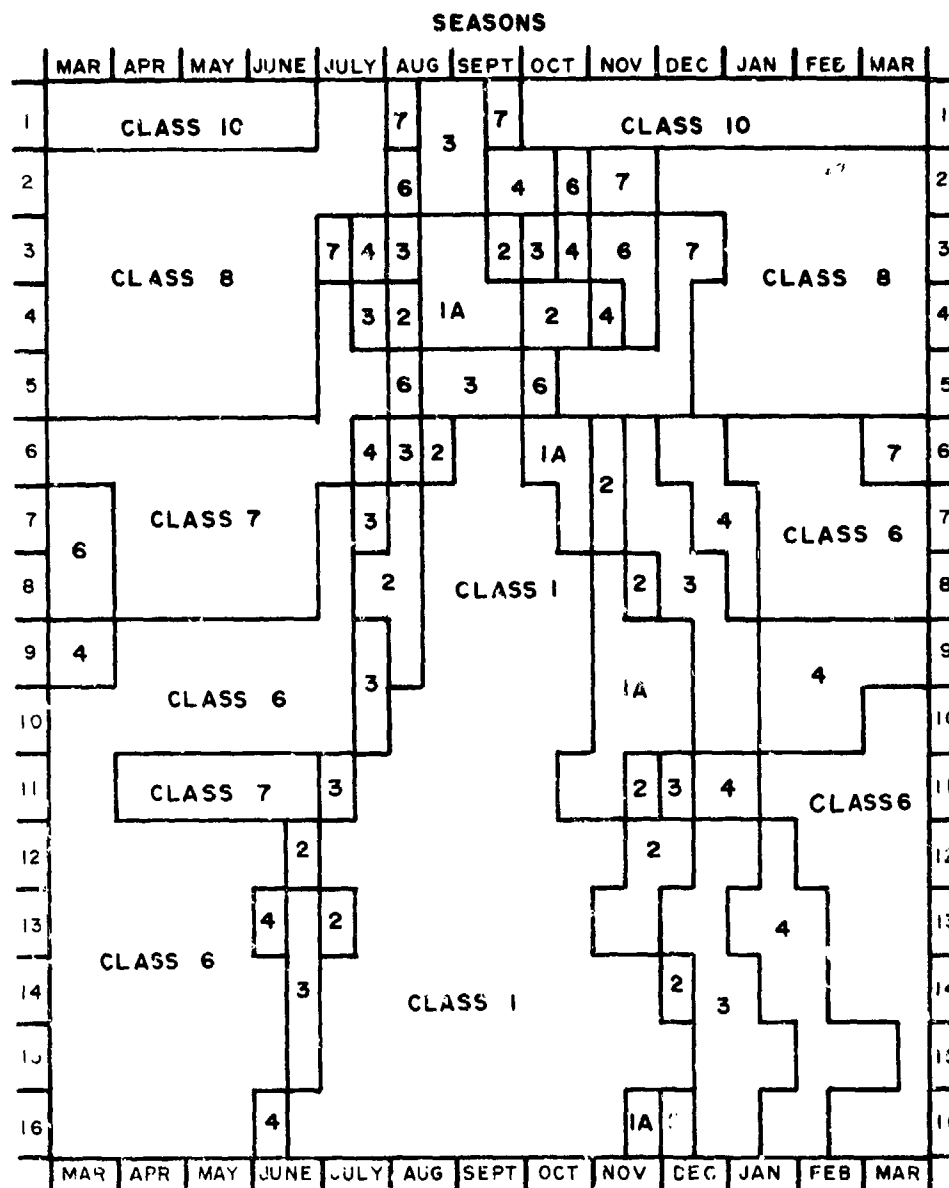


FIGURE 10

MINIMUM SHIP REQUIREMENTS BY ARCTIC SHIP CLASS FOR OPERATION IN THE
VARIOUS ICE CONTROL ZONES AT VARIOUS TIMES OF THE YEAR

Ice reconnaissance and ice reporting is accomplished by cooperative effort of two government agencies. The basic ice data is obtained from ice lookout stations. They report every day (during the ice season) on the ice conditions in their observation area. A second source is the several-times-a-day ice reports from the state icebreakers. Of increasing importance are the reports on ice conditions observed from the state icebreaker-based helicopters. Of course any ice information provided by merchant vessels is included and used. For the more general overview of ice conditions, satellite photos and observations from fixed aircraft are used.

The collected data are assembled into ice charts and weather forecasts and are transmitted by telegraphy, radio, teleprinter, radiotelephony, telefacsimile and television. These reports are provided daily (covering a 24-hour period) and, in addition, on a twice weekly basis, a 5-day wind and temperature forecast. Lastly, a conjecture of the ice development is made for the next 5-day period. The ice forecast is general and supplies very few details.

The icebreaking service is operated by the National Swedish Administration of Shipping and Navigation. The vessels are manned by the Swedish Naval forces and their main function is to break ice between open waters. Occasionally it is necessary to rent municipal and private icebreakers to assist.

Traffic is regulated in accordance with the Ice-Breaking Ordinance. Ships suitable for winter navigation can receive icebreaking assistance in coastal water and in the sea routes to these waters. The regulations require compliance with the ice-class designations and requirements for ice class and tonnage size.

Ice-class designations are for regulating traffic in certain ice conditions as shown in Table 9.

TABLE 9. Ice-Class Designations

<u>Ice Class</u>	<u>Ice Conditions</u>
IA Super	Extreme
IA	Severe
IB	Semi-severe
IC	Light
II	Very light

The requirements for ice class and tonnage size are shown in Table 10.

TABLE 10
REQUIREMENTS FOR ICE CLASS AND TONNAGE SIZE

Ice-Class	Tonnage	Requirement
II	At least 500 DWT	Prescribed when icing starts in ports and when there is obvious risk of ice at sea.
II	At least 700 DWT	Prescribed when icing has started along the coast and risk of ice pressure against the coast and in the approach channels
IC	Gradually increases	Prescribed when icing starts at sea and in sea constrictions

The dates of application are shown in Table 11:

TABLE 11
DATES OF APPLICATION OF REQUIREMENTS FOR ICE CLASS AND TONNAGE

Ice Class	Tonnage	Bothnian Bay	Bothnian Sea
II	500 DWT	1/11	1/12
II	700 DWT	15/11	15/12
II to IC	2000 DWT	15/12	15/1
IB	2000 DWT	1/1	1/2
IA	2000 DWT	15/1	15/2

By special permission only:

IA	2000 DWT	15/4	1/4
IB	2000 DWT	1/5	1/4
II	700 DWT	1/6	1/5

The winter ice research program considers work which will result in better and more reliable ice forecasts. The areas concentrated on are:

- a. Formation, growth and breakup of ice
- b. Surveying of the ice and its extent
- c. Movement and dynamics of the ice
- d. Ice deformation ridge studies
- e. Icing of vessels

At present a numerical model is being developed to predict the movements and redistribution of ice in the Bay and Sea of Bothnia. The objective is to provide more reliable ice forecasts for one to five days ahead.

4.4 Coast Guard Ice Navigation Center

Congress sponsored a very broad and extensive program to demonstrate the possibility of year-round navigation on the Great Lakes. The economic potential of all seasons marine transportation in the Great Lakes provided the major impetus.

The presence of ice mainly in the lakes, the waterways which connect them, including the locks, and the St. Lawrence Seaway, prevented or at the least impeded ship transit during four to six months a year.

The Coast Guard Ice Navigation Center served as a data accumulation, archive and clearing house for ice and weather information pertinent to shipping. The original data system included ice thickness measurements obtained at many Coast Guard stations around the Great Lakes and minimum aerial ice reconnaissance by Coast Guard aircraft with ice observers. The ice observers collected or mapped the concentration of ice using essentially the WMO (World Meteorological Organization) ice message format and symbolism.

This information was provided to the major shipping companies on request. Later in the program a combined effort by Coast Guard (CG) National Weather Service (NWS) and National Aeronautics and Space Administration (NASA) initiated a remote sensing data acquisition project. The product was a near real-time provision of radar images of ice conditions in the Great Lakes.

NASA provided a SLAR to be flown on a CG C-130. The objective of the program was to provide radar images and interpretive ice charts containing ice thickness to vessels in a near real-time mode to assist the vessels in avoiding ice areas that might impede transit.

The radar imagery was transmitted to the CG Ice Navigation Center, Cleveland, Ohio, using two communications networks.

First, a near real-time transmission from the SLAR aircraft to selected shore stations by a S-band microwave downlink and then to the Center by special dedicated telephone lines. Second, by a continuous real-time transmission from the SLAR aircraft to the SMS/ GOES satellite in geosynchronous orbit by a VHF uplink (from the aircraft) and a subsequent microwave downlink (from the satellite) to the Wallops Island, Virginia, ground station and then to the Center by dedicated telephone lines.

Once received by the Center, the SLAR data was used to generate a high-quality SLAR image. The SLAR image was then interpreted and prepared for presentation in the form of an ice chart. The ice charts also included ice thickness measurements obtained with the NASA short-pulse radar. The final product included the SLAR image with interpretive overlay including ice thickness and any other available ice information thought to be relevant. This product was then transmitted from the Center by facsimile to the Lorain, Ohio, MARAD and Central Radio Marine VHF network to be broadcast to vessels equipped with the appropriate facsimile receivers.

Some attempt to survey user opinion regarding the effectiveness of this system was made. The results of the survey are not known at this writing.

5.0 ICE AND WEATHER FORECASTING

For the purposes of this report ice forecasting is the major topic of this section. Weather forecasting is actually included as a part of ice forecasting because the meteorological conditions are the forcing or driving mechanisms for changing ice conditions.

The National Weather Service (NWS) has statutory responsibility for the preparation and the promulgation of ice forecasts and advisories for all but military purposes.

The U. S. Navy has, since World War II, maintained and developed a program the purpose of which is to routinely assess Arctic and Antarctic sea ice conditions. The program has resulted in the collection, accumulation, collation and synthesis of considerable quantities of data on ice conditions particularly in the Arctic. A product of the program has been the regularly issued reports which forecast expected ice movement and conditions.

NWS recognized in 1975 that the extremely "tough" ice conditions encountered by the 1975 North Slope resupply operation was just the beginning of a long-term requirement by the public sector for routine ice information services. Thus NWS initiated a program to improve its capabilities for a continuing effort in reporting and forecasting sea ice conditions.

The U. S. Navy through the Fleet Weather Facility, Suitland, Maryland, has collected information on sea ice from all pertinent global areas (especially Norway, Canada and the USSR). This information has been correlated and interrelated with meteorological and oceanographic forecasts to provide the basis for their routinely issued summary ice advisories. These reports of present and forecasts of future ice conditions have been distributed in facsimile and narrative formats. The reports have been available to Commander, Seventeenth Coast Guard District, CO's of Coast Guard icebreakers operationally in Alaskan waters; Navy commands; National Meteorological Center, Suitland, Maryland, and Naval Arctic Research Laboratory, Barrow, Alaska.

Because of the present and expected future demand for ice information services by the public (commercial shipping interests), NWS will by statutory responsibility assume many if not all of the ice data collection and analysis functions now performed primarily by the U. S. Navy. This, of course, will not happen overnight but will be an evolutionary process.

The role of the U. S. Coast Guard will be essentially as a data collector/contributor, user and communicator for the NWS ice information service.

To summarize and conclude this section, Tables 12, 13 and 14 have been assembled and are presented below. The data for Table 12 is taken mainly from Wittmann (1975) and adapted for this report.

Table 12 shows in a very general way the degree of need for ice information (particularly key features) by various broad categories of users.

TABLE 12

KEY ICE FEATURES RELATED TO THE DEGREE OF NEED BY VARIOUS USERS

USER	ICE THICKNESS	PRESSURE RIDGES	CONCENTRATION	ICE EDGE	FRACTURE PATTERN	ICE MOTION
ALASKAN RESOURCE EXPLOITATION	HIGH	HIGH	MODERATE	HIGH	HIGH	HIGH
SHIP DESIGN FOR ICE	HIGH	HIGH	HIGH	MODERATE	HIGH	HIGH
SURFACE EFFECT VEHICLE DESIGN AND OPERATION	MODERATE	HIGH	MODERATE	HIGH	HIGH	HIGH
SCIENTIFIC	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH

Table 13 gives a more extensive listing of key ice features that would most likely be required by an operational ice information system.

Table 14 provides a list of activities presently involved in processing sea ice information.

TABLE 13
LIST OF SOME KEY ICE FEATURES REQUIRED BY AN OPERATIONAL ICE INFORMATION SYSTEM

- Ice thickness
- Pressure ridges
 - sail height
 - keel depth
 - number per km
- Ice edge (boundaries)
- Floe (size frequency distribution)
- Concentration
- Age (multi-year, etc.)
- Icebergs/ice islands
 - height
 - draft
 - volume
- Fast ice
 - extent
- Water openings
 - leads (orientation, extent)
 - polynas (size)
- Snow (percent cover)

TABLE 14
LIST OF ACTIVITIES PRESENTLY INVOLVED IN PROCESSING SEA ICE INFORMATION

Suitland, MD

U. S. Navy Fleet Weather Facility
(Ice Services Department)
National Meteorological Center, NWS
Arctic Institute of North America

Alaska

Weather Service Forecast Office, Fairbanks
Weather Service Forecast Office, Anchorage
Weather Service Forecast Office, Juneau
National Environmental Satellite Service,
Anchorage
Commander, 17th Coast Guard District, Juneau
U. S. Coast Guard Icebreakers, Barrow Area
U. S. Navy Arctic Research Laboratory, Barrow
Commodore, North Slope Resupply Force
Military Sealift Command Office, Anchorage
Alaska-Puget United Transportation Company

Seattle

Seattle Ocean Services Unit, WSFO Seattle
Arctic Marine Freighters (Crowley Maritime)

San Francisco

National Environmental Satellite Service

Canada

Arctic Weather Central, Beaufort
Ice Forecasting Central, Ottawa
Ice Branch, Downsview, Ontario
Ice Operations Office, Toronto
Ice Operations Office, Montreal
Ice Operations Office, Halifax
Ice Operations Office, Frobisher Bay

6.0 ICE RESEARCH PROGRAMS

Ice research in the Arctic can be arbitrarily divided into large-area, long time frame studies and small-area, short time frame studies. AIDJEX is an example of a study program which addressed both area scales and time frames for the purpose of obtaining knowledge of the motion of the Arctic ice cover.

The large-area, long time frame studies are essentially concerned with topics like determination of the stability of the Arctic Sea ice cover; the volume, condition, and dynamics of the sea ice cover; and development of numerical models which describe the interaction of the atmosphere and oceans and the subsequent effect on the sea ice cover and ultimately the consequences to world climate.

Small-area, short time frame studies are concerned with the physics of ice and how an understanding of it can be applied to the solution of practical problems such as design of icebreaking ships and ice resistant or tolerant structures.

Logistics becomes the go/no-go decision maker for most ice research. This is because the vast geographic area and extreme cold of the Arctic are not amenable to doing things without maximum hassle. Thus most studies of Arctic problems are contained within or under the umbrella of a large program. The large program can have an identified logistics function which expedites the operational aspects of any field experiment. Examples of programs of this nature are the IGY effort in the Antarctic, AIDJEX, POLEX and the Nansen Drift Study. Within each of these programs many individual investigators can perform experiments that could not be done without the centralized logistics.

By far the grandest of all and most recent large-area ice research program is the multi-agency sponsored AIDJEX. AIDJEX is the acronym for Arctic Ice Dynamics Joint Experiment. The preliminary plan was prepared in 1969 and progressed to the final plan by 1972. Two pilot field experiments were conducted in 1970 and 1971. The main one-year field program ran from March 1975 to May 1976. This program is in the final stages and has been reported in the symposium Sea Ice Processes and Models, 6 to 9 September 1977.

The AIDJEX program set out to answer four questions.

1. How is large-area ice deformation related to the external stress field?
2. How can the external stresses be derived from a few fundamental and easily measured parameters?
3. What are the mechanisms of ice deformation?
4. How do ice deformation and morphology affect the heat balance?

This program was expensive and was indeed a very large effort. It was the consensus of the representatives of the scientific community who attended the symposium that the AIDJEX effort resulted in a quantum jump in knowledge and understanding of ice dynamics.

More substantial proof of this increase in knowledge is shown by the very extensive inventory of data that was collected and is archived in the AIDJEX Data Bank.

At this point other questions become of interest concerning how well did the original AIDJEX plan address and answer the original questions. These new questions are:

1. Were the scales of observations chosen correctly?
2. Were the right observations taken?
3. Was it possible to deduce the external stresses to sufficient accuracy?
4. Did the model development advance understanding of sea ice mechanics and heat balance?

The answer to these four new questions is tentatively yes, again, by consensus.

By comparison, the POLEX and Nansen Drift (the proposed Nansen Drift, not the 1893 to 1896 one) are not of the same magnitude of effort as AIDJEX although the Nansen Drift may evolve into it.

Future ice research will concentrate on providing the scientific basis for application of technology to user-oriented activities. Some of the areas are addressed below.

Remote sensing of the environment will figure strongly for satisfying the needs of various users of the Arctic regions. Satellite-mounted sensors are being developed and improved for many diverse uses from ice edge location to pressure-ridge sail-height census to possibly ice thickness. Already microwave instruments used from aircraft can provide categorical, not precise, ice thickness. Airborne remote sensors especially SLAR are well on the way to operational use. However, some very necessary research is still to be done on just how to interpret SLAR imagery of ice.

Many areas of acoustics are in the wings and should be examined with respect to ice. Studies of ambient noise, reverberation and transmission losses are necessary because they are very poorly understood.

The design of icebreaking oil tankers and LNG carriers is essentially poised on the verge of launch awaiting the results of test and evaluation of the POLAR STAR. This program is one of the most extensive and thorough of any before and possibly to come. Various misfortunes have delayed the execution of this program but even minimum success will represent a giant step forward in ice research concerning the design of icebreaking vessels.

Many more basic research problems must be addressed in the future. Specifically, they are ice properties measurement problems. For example, development of techniques to obtain unambiguous small-sample ice strength measurements. Other examples are techniques to measure ice field pressure, friction of ice and snow on the steel hull of a ship, methods to characterize pressure ridges that convey the necessary information to a ship's master for assuring safe and efficient ice passage. These are but a few of the many possible areas where ice research is not only desirable but in some cases mandatory.

7.0 SUMMARY

The U.S. Coast Guard, as part of the Department of Transportation, has many responsibilities for maintaining and increasing the capability and capacity of a national marine transportation system. The various laws, executive orders, etc., which direct the Coast Guard's effort are a matter of record. At this point it is enough to know that further development of Alaskan oil will require icebreaker support and that the U.S. Coast Guard has the sole responsibility for icebreaker and icebreaking (polar) operations. In addition, the search and rescue and aids-to-navigation functions in the Western Arctic are primarily Coast Guard responsibilities. Not the least to be considered is the obligation by statute and capability to address the marine environmental pollution problems. All of these activities must be executed with limited resources at a time when present Coast Guard resources are already strained and future projections suggest more of the same. Thus with increasing demand for services, the utilization of limited resources must be well organized, efficiently and effectively directed and executed. To collect thoughts here, the basic need is to exploit the energy reserves of Alaska and the Western Arctic which will depend on marine transportation which, because of the ice and generally inhospitable environmental conditions, requires icebreakers and icebreaking services. The Coast Guard is responsible for provision of these services and, because it has limited manpower, facilities and equipment, it must have a well-planned systematic approach to satisfy the many requirements. To satisfy these requirements a Polar Vessel Information System becomes a dynamic tool for the Coast Guard's need to allocate its limited resources commensurate with increasing demand for services.

This report has presented a reasonable and some extreme projections of commercial maritime activity in the Western Arctic. These projections can be used to develop statements of requirements. Details will not be attempted here but must await further study. For the present, numbers from Table 5A give a general order of magnitude idea of the basis for determination of a requirement. These numerical projections of vessel traffic density combined with the reasons given in the following paragraphs provide some justification and encouragement to consider the development of a Polar Vessel Information System. The timing required is essentially immediate if the reasonable projections are realized.

Commercial marine activity will increase dramatically in the Western Arctic commencing about 1980. This conclusion is based on the projected rate and extent of exploitation of the natural resources (particularly petroleum) of the Western Arctic. The consequence of this increased maritime traffic will be continued increasing demand for the marine services provided (under statutory authority) by the U.S. Coast Guard. The services required are primarily in the areas of search and rescue, aids to navigation, icebreaking, and marine environmental protection.

One of the stated objectives of the Polar Vessel Information System program is to develop an environmental conditions advisory and coordination facility service for commercial vessel traffic and Coast Guard icebreakers in the Western Arctic. The development of an environmental conditions advisory and coordination facility service is the statutory responsibility of the

National Weather Service (NWS). NWS, in 1974, initiated a program addressing the need to improve their capabilities to provide ice information services to the commercial fleet in the Western Arctic. Thus the Coast Guard does not need to address this objective.

The demand for Arctic search and rescue services will be great and ever increasing in step with the offshore oil development and the introduction of icebreaking oil tankers and LNG carriers.

Concurrent with the introduction of oil and LNG carriers and offshore drilling will be increased allocation of Coast Guard resources to the marine environmental protection functions. A part of this responsibility not immediately obvious is the increased requirement for marine inspection to assure compliance and thus prevention of major marine disasters in the hostile but fragile Arctic waters.

Increasing numbers of large and specialized vessels which will attempt year-round transit of ice-covered Arctic waters will require greatly expanded vessel traffic control and extensive aids to navigation. In these areas the Coast Guard must carry the greatest proportion of responsibility.

The magnitude of projected maritime activity will require a centrally located facility which effects operational awareness and control of all functions required (particularly of an advisory nature) to expedite marine transportation. This coordination function is vitally important to the national interest in the Western Arctic. Exactly what organization (agency, etc.) will perform this coordination function is now known. The Coast Guard by virtue of experience and statutory responsibility in most of the expected marine functions required have the necessary capabilities to be the lead agency.

8.0 SCENARIO OF A POLAR VESSEL INFORMATION SYSTEM

Briefly, by way of outline, the Coast Guard is responsible for enforcing laws and treaties, conducting ice operations in support of the Department of Defense, National Science Foundation and other agencies (Federal and state) and commercial marine commerce, providing search and rescue, aids to navigation and marine environmental protection services. Within and between the above listed areas of responsibility are included many complex problems. The solution to these problems must be found by coordinated effort which results in both efficient and effective operations.

The coordination can be accomplished by identifying, defining and describing the problems and organizing them into an operational system. This system will be called a Polar Vessel Information System. Of course the system would be composed of numerous subsystems and components, each concerned with a specific problem area such as ice operations or aids to navigation, etc.

Some general comments follow on the description of a total system, but the emphasis will be placed on describing an environmental conditions advisory and coordination facility for commercial vessel traffic and Coast Guard ice-breakers in the waters of the Western Arctic.

Describing a system begins with consideration of some basic questions. Is there a need? What is needed? Who would use it? When and where would it be used? How would it be used? These questions can be answered; some with facts and others by speculation.

The need for a system may not be obvious at least until some of the complex interrelationships are recognized and some understanding of the very broad scope of the problem is obtained. Basic to establishing the need for a Polar Vessel Information System is recognition and awareness that the United States is experiencing an economic upheaval caused by the energy crisis. The Executive Branch of the Federal Government is committed to directing the U. S. toward more, if not total, reliance on domestic energy sources. Exploitation of Alaskan energy resources and the efficient and effective transportation of them is certainly a very important part of achieving domestic energy self-sufficiency.

What is needed is specific for this study; determine the feasibility of developing an environmental conditions advisory and coordination facility service for commercial vessel traffic and Coast Guard icebreakers in the Western Arctic. In a broad sense, much more is needed and describing or attempting an exhaustive accounting of what is needed is beyond the present effort.

The question of who would use a Polar Vessel Information Service is answered in general terms. The primary user is Coast Guard's Office of Operations. Eventually, every commercial marine enterprise operating in Western Arctic waters would make use of the system.

The system would be used additionally in the Bering, Chukchi, and Beaufort Seas. It might also extend to the Alaskan rivers and later to other seasonally ice-covered domestic waterways such as the Great Lakes.

How it would be used is a difficult question to answer without first having a reasonably detailed description of a system. For now it is likely that the user would receive information that is accumulated within the system, then analyzed and communicated via facsimile to the ship. The information would be a near real-time description of ice and weather conditions with suggested optimum routing.

8.1 Polar Vessel Information System

The following will attempt to describe, in some detail, a system, the main purpose of which is to promote safe, efficient and effective marine transportation in ice-covered waters, particularly the Western Arctic.

The formal language of systems analysis will be used in an essentially indiscriminate manner throughout this discussion. From the engineering point of view a complex multi-port system will be described without using bond graphs to do so. Bond graphs are more abstract than the more common "wiring" diagram but they have the advantages of being explicit and using a common set of symbols for all models of the same or similar systems. In the future development of the Polar Vessel Information System (PVIS), the more formal systems techniques and language would be used.

The first step in describing a system, after defining what the system is for, is to break it into smaller, more tractable parts called subsystems. Further subdivision into components may be necessary depending on degree of detail desired. Subsystems and so on can usually be considered as systems within themselves. This discussion will consider subsystems as major parts of the PVIS system and components will be considered primitive parts of the subsystems. The division implied by this hierarchy is not absolute, only convenient.

PVIS would be an operational system. This implies a number of functions: information collection, evaluation, retention and communication. Figure 11 is a generalized diagram from NWS and ships of opportunity of PVIS. The diagram shows the subdivision of PVIS into four subsystems. These subsystems are further broken down into components.

PVIS would consist of many components most of which would functionally operate within the confines of a single facility. The facility for the Western Arctic would probably be located in the Seventeenth Coast Guard District headquarters, Juneau, Alaska.

The facility would be very similar to present RCC facilities; the major difference would be quantity and sophistication of computing and communications equipment. This facility would be called Ice Transit Vessel Information Center (ITVIC). The primary function would be to inform any and all ships of the present and expected ice conditions and other route information necessary for the planned operating area.

ITVIC would receive complete ice and weather information from the National Weather Service then prepare by reformatting or whatever is thought necessary for a navigation status chart for transmission to all operating vessels. Navigation status charts would be prepared for various scales. The largest scale charts would show detailed information about ice concentration, thickness, openings (leads), Navaid's operating, and vessel assistance available for individual harbors or approaches. The small-scale navigation status charts would provide less detailed, although the same categorical, information as the large-scale charts and in addition would annotate suggested routes for the specific operating area requested.

ITVIC would also keep track of vessel positions and status in the event search and rescue might be required. This position status information could also be used to minimize the effects of a pollution incident by being ready to deploy containment and cleanup equipment and forces to the scene without unnecessary time lost for search.

Many non-existent information sources like shore-based-remote-ice-scene/Navaid radars and bottom-founded acoustic Navaid's would have to be developed to realize the full potential of PVIS.

These and other novel and not so novel approaches to solution of Arctic vessel transit and control problems can be addressed in a technical development plan.

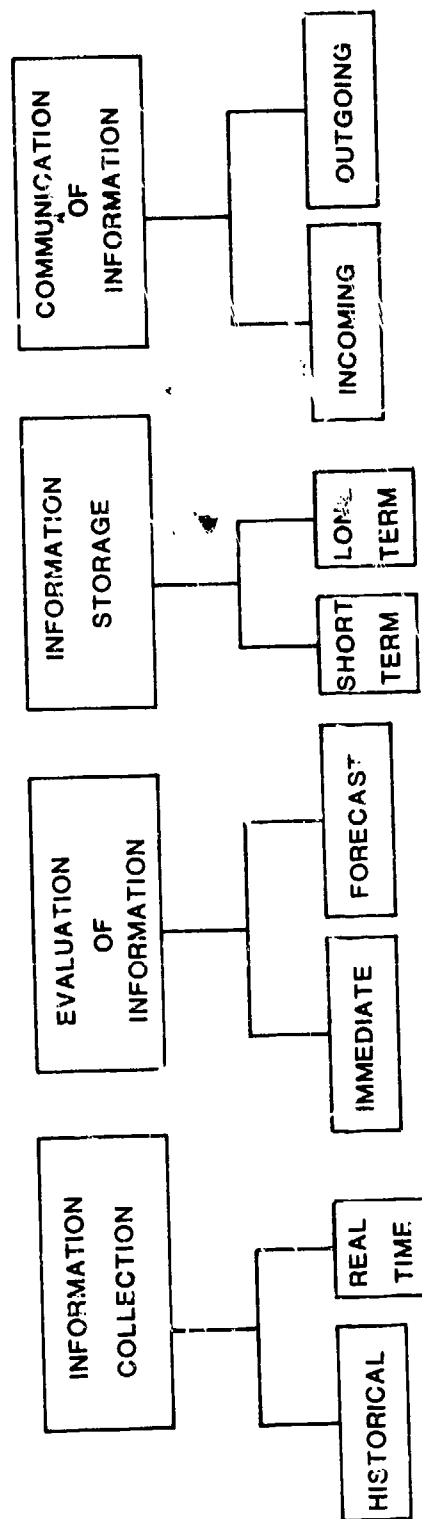


FIGURE 11
COMPONENTS OF THE PVIS SUBSYSTEMS

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